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Investigating Possible Scurvy in the Postclassic Maya of Tipu

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INVESTIGATING POSSIBLE SCURVY IN THE MAYA OF TIPU

by

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ABSTRACT

Although residing in a tropical environment, numerous researchers have posited the possibility of scurvy in the Maya in recent years. The historic population of Tipu in western Belize dating to AD 1541-1638 is one of the largest and best preserved Maya series, and was therefore evaluated for possible presence of scurvy since the diet appears typical of the pre-contact Petén populations. The temporal bones and greater wings of the sphenoid were analyzed for scorbutic activity in 143 individuals, along with periodontal disease and antemortem tooth loss to determine if there was a co-occurrence with scurvy.

Overall, 27% of the sample showed indications of mild scurvy. In age comparisons, sub-adults between 6 and 15 had the highest rate of lesions at 33% affected, and those over 30 had the lowest at 16 %. Adult males were more likely to display symptoms of scurvy with a prevalence of 29% as compared to females at 21%. Approximately half of all individuals with scurvy displayed lesions on both the temporal and sphenoid, with 97% of adults with scurvy showing a co-occurrence with periodontal disease.

This data suggests Tipu experienced scurvy, but the frequency was low and severity was relatively mild. One potential cause, despite living in a tropical environment, is Maya food processing practices and possibly their food preferences. The findings also suggest that scurvy and other similar conditions should be kept in mind when interpreting health status since their symptoms may be acting synergistically with other nutrient deficiencies to compromise the immune system.

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DEDICATION

First, I want to dedicate this thesis to my late grandparents, Edward and Helen Gomberg, who made it possible for me to obtain my undergraduate degree and to pursue my graduate degree. Without their support none of this would have been possible, and for that I will always be grateful.

Next, I want to dedicate this thesis to my parents and my sister. I would not have been able to finish without their emotional and financial support. I regret that, in many ways, I have not made the last five years easy for you. There isn’t enough I can do or say to thank you or show my appreciation in a way that you truly deserve. I love you so much, and I hope that I have made you proud.

Finally, I want to dedicate this thesis to the loved ones that are no longer with us, Sylvia Danforth, my grandparents, and to Doc, Eliza, and Drew. You are all missed.

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CHAPTER I – INTRODUCTION

Population stress and health has been a principal topic of investigation in anthropology for many years. Studying these concepts in living groups can reveal much about a culture, but it poses somewhat of a challenge in the bioarchaeological setting. Various theories such as the Osteological Paradox (Wood et al. 1992) touch upon a few of the issues that can be encountered. However, new information regarding markers and causes of stress and health, arguments about the definition of these terms themselves, and their interpretations have pushed investigations into more productive contexts. They have also opened up past studies of this nature to new questions.

These concepts have been investigated in widely known paleopathological conditions, such as cribra orbitalia or porotic hyperostosis, to understand the causes and consequences of population stress and health, but far less is generally known about many other conditions that are less severe in their consequences or are not as easily studied using skeletal indicators. Many of these latter health challenges, however, occur synergistically, taking place with or being caused by other deficiencies. For example, a vitamin D deficiency can lead to a calcium deficiency, causing conditions like osteoporosis to worsen. In other cases, nutritional deficiencies can compromise the immune system, making individuals susceptible to certain infectious diseases that they might otherwise avoid (Chandra 1997). Furthermore, those who are sick often are afflicted with symptoms such as poor appetites, vomiting, and/or diarrhea, all of which can affect consumption of foods that carry needed nutrients. Therefore, these lesser-studied deficiencies are essential to understanding the larger picture when it comes to the relationship between health and culture.

One of the deficiencies that recently has received increasing attention in paleopathological research over the past few decades is scurvy (Crandall and Klaus 2014; Klaus 2015; Ortner 2003; Ortner et al. 2001; Ortner and Ericksen 1997; Ortner, Kimmerle, and Diez 1990). The condition is caused by the lack of Vitamin C in the diet, which is an essential cofactor in collagen synthesis and immune system function. Clinically, the deficiency is most commonly associated with bleeding gums, gingivitis, and tooth loss (Hirschmann and Raugi 1999). On the paleopathological level, scurvy can be expressed on a number of postcranial elements in the skeleton, but is most often diagnosed through presence of porosities on key cranial bones that are caused by muscle action on a weakened periosteum (Ortner 2003).

Typically, scurvy is not expected in populations from tropical environments due to the presence of many local resources rich in vitamin C, but there are a number of factors that could contribute to the appearance of scurvy in this type of setting. Wrobel (2014) discusses some of these reasons, including heat from cooking that breaks down vitamin C content and a cultural preference towards foods low in ascorbic acid. Environmental factors could also affect the seasonal production of these sources that are high in vitamin C (Behie and Pavelka 2005). Therefore, the assumption that tropical environments are less likely to experience vitamin C deficiency may not necessarily be valid.

The Maya are one of the tropical populations for whom scurvy has been sporadically reported (Saul 1972; White et al. 2006; Wrobel 2015), but none as of yet have been systematically evaluated for its presence. The historical Maya site of Tipu, located on the Macal River in western Belize, however, offers an excellent opportunity to undertake such an evaluation due to its large size and good preservation. Excavations of this site in the early to mid 1980s recovered over 500 individuals who were buried inside and around what appeared to be a Spanish *visita* mission (Cohen et al. 1997). The series has since undergone extensive evaluation for a variety of demographic and health markers (Cohen et al. 1994, 1997) and represents one of the best studied Maya populations in general.

Porotic hyperostosis and cribra orbitalia were previously observed in the series in the late 1980s, and were interpreted as evidence of anemia, following longstanding tradition for that skeletal marker (Cohen et al. 1997; Ortner 2003). Since then, especially with the development of more detailed scoring standards, several new explanations for the cause of cranial porosities have emerged, one of the primary ones being scurvy. Lesions suggestive of scurvy were noted in a pilot study of the Tipu population (Gomberg 2017), and the focus of this project was to evaluate the presence of the deficiency at the site on a larger scale. It analyzed the severity and frequency of lesions based on age, sex, and the population level as a whole, examining the squamous portion of the temporal bones and the greater wings of the sphenoid. It also investigated the co-occurrence of the lesions associated with scurvy with pathological markers associated with periodontal disease, and considered various cultural contexts that might result in vitamin C deficiency in a tropical environment.

The findings from this study will provide insight into the diagnosis of scurvy and help lead to the development of a more standardized scoring method for lesions than currently exists. This project also looks at aspects of Maya culture that may have contributed to the presence of the condition in an environment with abundant sources of ascorbic acid for consumption and considers whether levels of scurvy might have been affected by the effects of Spanish contact. Lastly, it contributes to a better understanding of scurvy in the bioarchaeological record. There is a shortage of research concerning scurvy compared to other conditions such as cribra orbitalia and porotic hyperostosis despite its potentially large impact on health. Therefore, an appreciation of its presence in a large population, especially one where scurvy is not even anticipated to be found, will be a valuable addition to the paleopathological literature.

CHAPTER II – TIPU: ETHNOHISTORY AND PREVIOUS INVESTIGATIONS

European contact in Central America marks one of the most significant periods of human history in terms of major cultural change. Many indigenous Central Americans were wiped out by diseases or violence brought on by the Spanish; however, a small area in Belize known as Tipu managed to persist well throughout the contact period. This chapter will discuss various aspects of Tipu, including the ethnographic history of the area and its people, the discovery and excavation of the archaeological site, as well as the site demography and previous paleopathological investigations of the population. This information will help to create a picture of the life experiences of the Tipu people, including the cultural, health, and sociopolitical aspects of their lives, in order to better understand why they may have suffered from scurvy.

Ethnographic History of Tipu

Before Contact

Little is known about Tipu and its people before contact, but ethnohistorical research suggests that Tipu was the capital town of the Dzuluinicob province at the time (Graham 2011; Jacobi 2001; Jones 1989), which was located on the banks of the Macal River in western Belize (Figure 1). Scholes and Thompson (1977) believe that Tipu was inhabited by a group called the Muzul on the basis of a list of Maya names in the Francisco Perez *Probanza* (Jones 2014). Ceramic evidence found in a Post-classic structure also links them to the Itzá and Kowoj of Petén (Cecil 2001, as cited by Graham 2011). More documents reveal that Tipu was a major player in cacao cultivation and trade, and one study confirmed that it was the likely site of a large cacao orchard (Jones 1989; Muhs and Kautz 1985; Thompson 1977).

Figure 1. Location of Tipu and Other Important Maya Sites. (From Harvey et al. 2016***).***

First Contact

The Spanish held an interest in Tipu because of their ties with the Petén Itzá and the town's vicinity to Lake Petén. The Spaniards had yet to reach Guatemala, and they needed to gain control of Tipu in order to reach the Itzá. In 1544 the Spanish established Tipu as part of an *encomienda,* and a chapel was built as the last part of a string of missions that were overseen by the Spanish who settled at Salamanca de Bacalar. This *encomienda* required Tipuans to provide labor and tribute to the Spanish, but the isolated location of the town on the frontier made it difficult for the Spaniards to control (Jacobi 2001). Little is known about the activity at Tipu in the short period after the *encomienda* was established, but rebellion broke out between 1546-1547 in other established *encomiendas* in northern Yucatan including Chanlacan, the capital of what was the former Chetumal province that neighbored Dzuluinicob. This violent rebellion prompted thousands of the northern Yucatec Maya to flee and seek refuge in the Southern Yucatan communities, which included Tipu (Jones 1989).

Tipu at Risk

In response to this rebellious activity, the Spanish launched a massive *reducción* effort throughout the region, establishing various sites where the Spanish would aggregate smaller Maya populations in order to control and monitor their conversion to Christianity (Jacobi 2001; Jones 1989). Tipu was established as one of these *reducciónes* in 1568 after Maya "idols" and codices were found during an *entrada* The Spaniards destroyed the idols, burned their books, and punished Maya priests who were not practicing or spreading Christian doctrine. Two more *reducción* efforts were focused on Tipu in 1608 and 1615, but it was still difficult to maintain control, as it was the most distant mission from Bacalar (Graham 2011; Jones 1989). However, Jones (1989) points out that Tipu must have been important enough to the Spanish to put in this level of effort to monitor a Maya town that sat at the edge of the Spanish frontier.

Two Franciscan friars traveled to Tipu in the early 17th century to help facilitate the conversion efforts (Jacobi 2001). Archaeological evidence suggests that the Tipuans were adopting the Christian practices, at least nominally. Christian style burials were found at the site along with Christian artifacts, including a Spanish style censer (Graham 2011). Tipuans were attending Mass and sent their children to the friars to learn the religion. This led the friars to believe it was a good time to ask the Tipuans to facilitate a meeting with the Itzá of the Petén, and they were eventually invited to meet with the Itzá at Tayasal. After a failed attempt at converting the Itzá, one friar became so upset that he destroyed an Itzá idol of a horse (Jacobi 2001). This did not leave the Itzá with a favorable impression of the Spanish or Christianity, and likely had a negative effect on future interactions between the Spanish and Itzá of Tayasal.

Resistance

Upon their return, the friars found that the Tipuans had continued indigenous practices, which furthered their building suspicion of an alliance forming between Tipu and the Itzá (Jacobi 2001; Jones 1989). Out of fear of losing control of the cacao production and their connection to the Itzá, the friars turned to the Spaniards at Bacalar for help (Jones 1989). Again, the Spaniards burned their idols and physically punished Tipuans who were thought to be facilitating the resistance against Christianity and the Spanish. This aggressive attempt by the Spaniards to make an example of Tipu for other areas that were not making progress towards Christianity seemed to cause the Tipuans to become compliant, but only superficially. Instead, this aggression caused them to become more covertly involved with the Itzá in rebellion activity against the Spanish. The friars attempted a second visit to the Itzá a year after their failed trip, and found that a cross was erected upon their arrival, giving hope that the Itzá had finally accepted Christianity. Despite the friars' best efforts, the Itzá began to rebel against the Christian teachings and eventually forced the friars to leave in a violent altercation (Jones 1989; as cited by Jacobi 2001). In 1623, friar Diego Delgado made a third attempt to convert the Itzá. He and a party of Spaniards rode to Tayasal and were promptly massacred on site. By 1624 another group of Spaniards were massacred by the Maya in an area called Zalculu (Graham 2011; Jacobi 2001).

Rebellion

Violence and rebellion began to escalate within the region in response to the poor treatment and extortion of the Maya by the Spaniards (Jones 1989). For the most part, Tipu resisted the Spanish influence in a covert and non-violent manner until a full on rebellion broke out in 1638 and they burned down their church (Graham 2011; Jacobi 2001). Other Maya groups, including those from Manan, claimed to have been threatened by Tipu and told to abandon their towns (Graham 2011). They continued to threaten other Maya groups, which resulted in the abandonment of eight towns that were controlled Bacalar, and the Spanish eventually lost control of the region in 1642 (Jones 1989).

Aftermath

The subsequent rebellions that broke out in Campeche in 1668 and 1678 had consequences that were felt in Petén and Belize, but Tipuans managed to avoid the Spanish for decades (Jones 1989). However, the attitude towards the Spanish seemed to change by 1695 when the Itzá started to use Tipu as a base to establish cooperation with the Spanish. A year later construction began on the Camino Real, a road connecting the Spanish missions in the area that would bypass Tipu and lead straight to Lake Petén Itzá (Jones 1989). With Tipu's newly established cooperation, the Spanish followed the Camino Real and captured Tayasal in 1697 in full force, but most of the Maya fled to the mountains escaping the Spaniards. By 1707 Tipu was forcibly relocated to Lake Petén because it was easier for the Spanish to control. There are also accounts of the Spanish forcing the Tipuans into labor, as well as kidnapping them and sending them into slavery with the British. One of the last known events at Tipu was an attack by the Muzul in 1708 where several important leaders of Tipu were killed (Graham 2011).

Cultural Continuity in the Midst of Contact: Foodways and Subsistence

Although European contact had a profound influence on indigenous cultures in the New World, the location of Tipu on the frontier gave them much more independence as they adapted to the Spanish presence (Harvey et al. 2016). Extensive syncretism occurred with religious beliefs, and many Maya lifeways continued to persist at Tipu despite European contact. Tribute payment, for example, had long been essential in Maya political and economic systems (Jacobi 2001). Subsistence practices also appear to have been little changed (Emery 1990; Graham 2011). Cacao continued to be their major agricultural product as it was a valuable trade source for both the Spanish and the Itzá of Peten (Graham 2011). Faunal sources of food included deer, turkey, and turtle, all of which were found at much earlier sites such including the Pre-classic/Classic site of Caracol (Emery 1990; Teeter 2001). Crops such as maize, beans, squash, manioc, and chili peppers were staples in their diet and had been since the Pre-classic period (McKillop 2004; Powis et al. 2013; Wiseman 1983).

Ethnohistoric accounts of Maya food processing and preparation during the Post-classic and Colonial period in Belize are few. It is likely that some cultural continuity in food preparation occurred, especially since diet appears to have stayed relatively consistent. Maize was processed via grinding with *manos and metates,* and was often made into tortillas by grilling on *comales* (Heath 2013). Chili peppers, spices, and some fruits and vegetables were ground using a type of mortar and pestle called a *molcajete,* while manioc was grated or grilled (Heath 2013; Wiseman 1983). Jar-shaped vessels called *ollas* and *tecomates* and large pots were used for boiling and stewing (Heath 2013).

All too often the large degree of cultural continuity is not appreciated given the focus on the upheaval that European contact brought. The Tipu people lived through one of the most significant times in history, but subsistence, ceramic production, and other aspects of their culture managed to persist intact through such a tumultuous period. Overall, Tipu was a population that held hard to lifeways despite the major cultural challenge that the Spanish presented.

Archaeological Site History

Location, Discovery, and the First Excavation

After the abandonment of Tipu, its specific location became lost in the ethnohistoric records. Sir Eric Thompson's research using various historic documents can be attributed to establishing the importance of Tipu and finding the location of the lost site. On the basis of Thompson's work and his own research, Grant Jones began the search for Tipu in an area known locally as Negroman, found in the Cayo District in west-central Belize (Graham et al. 1985; Jacobi 2001; Jones et al. 1983; Scholes and Thompson 1977; Thomspon 1977). Accompanied by David Pendergast, they began the search at a small cattle farm located near the west bank of the Macal River. As they examined the land, they identified what seemed to be evidence of a Pre-contact period structure beneath the soil. This discovery led to the first phase of archaeological investigations by Jones and Robert Kautz in 1980 (Graham 2011).

The first phase of excavations took place between 1980 and 1982 under the direction of Jones and Kautz (Graham 2011; Jacobi 2001). They were assisted by Claude Belanger who mapped the site and associated architecture. At first, only Pre-contact architecture was identified until a mound situated at an east-west orientation with a small concentration of cobblestones was found (Graham 2011; Graham et al. 1989). Preliminary excavation of the mound revealed architecture, which prompted the archaeologists to conduct test pitting (Graham 2011). These test pits eventually uncovered a *ramada* chapel and its associated cemetery, including human remains (Graham 2011; Jacobi 2001). The identification of the church with burials under the nave strongly suggested they had indeed located Tipu, but further excavations would confirm their find.

The Second Excavation: Architecture and Artifacts

The second phase of excavation began in 1984 under the direction of Elizabeth Graham and Mark Cohen. Cohen and his students from SUNY-Plattsburgh were tasked with the responsibility of excavating and analyzing the remains of the interments, while Graham focused primarily on the excavation of the church structure (Graham 2011; Jacobi 2001). Kautz was able to identify the church as a *ramada* style chapel with parallel sides and polygonal edges (Graham et al. 1991; Jacobi 2001). His excavations exposed that the church was built in at least two phases, which is consistent with the timing of the *reducción* efforts in Tipu during the 1560's (Cohen et al. 1997; Graham 2011, 1989; Jacobi 2001).

By the end of the 1984 season they partially uncovered an associated plaza near the church with smaller structures oriented around it, as well as buildings between the plaza and a Post-classic ceremonial center to the east called Complex I (H12-1 through H12-4) (Graham et al. 1991) (Figure 2). Architectural evidence suggests that this complex was a variant of a neighboring Petén group called the Kowoj (Cecil and Pugh 2004; Rice 2009). The largest structure (H12-8) was a thatched building that was likely home to important guests in the town. Two small structures that were uncovered on either side of the church are thought to house visiting priests. The *principales* of Tipu likely owned the two structures (H12-12, 14) found at the south of the plaza, while another house (H12-7) where a chest lock plate was found was likely where the sacristan lived (Graham 2011). Three other structures (G13-13,46, and 17) were found with human remains that could suggest occupation in during the Classic period (Emery 1990).

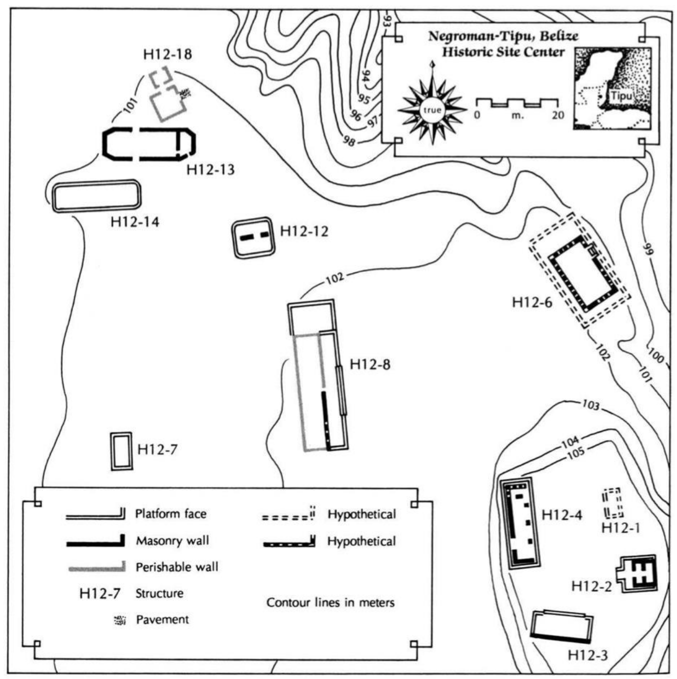

Figure 2. Map of Tipu Historic Center. (From Graham 2011, p. 206).

There were a number of different artifacts classes found at the site including ceramics, lithics, and grave goods. Ceramic artifacts were found in the Colonial site center and dated from the Post-classic through the Colonial period (Graham 2011); they included both Maya and Spanish varieties. The earliest pottery found in the Colonial area of the site were Post-classic Itzá and Kowoj ceramics found in Complex I. There was a higher frequency of the Kowoj ceramics, which indicates that Tipu may have had greater ties with the Kowoj while the complex was in use during the 16th century. The Terminal Post-classic/Colonial Lamanai style Yglesias ceramics were also found in the Colonial center. Not only did Post-classic styles persist throughout contact, but also the appearance of the Yglesias style pottery suggests that interactions between Tipu and Lamanai increased in the Colonial period (Cecil and Neff 2006; Cecil and Pugh 2004; Graham 1991, 2011). Ceramic censers were also recovered, lending credence to the continuity of Maya culture throughout contact as well as evidence of rebellion against Christian practices (Graham 1991, 2011; Jacobi 2001). The few Spanish imports included olive jars and Majolica plates, and were likely used by Spaniards or Christianized Tipuans (Graham 1991, 2011).

Simmons (1995) analyzed the lithic material recovered from the site. Much of this was recovered from the post-abandonment accumulation, with a few found in burial contexts, Colonial middens, and other contexts. The majority of the formal tools were small points that were likely used for arrows and small bifaces possibly used on spears or as multipurpose tools. Chert and obsidian were both used in manufacturing. Simmons inferred that the bow and arrows were used as weapons during the rebellion and as hunting tools (Emery 1990; Simmons 1995). Evidence of similar tools, specifically the small, side-notched projectile points, has been found at other regional Terminal Post-classic sites suggesting continuity in stone-tool manufacturing into the Colonial period (Graham 1991; Simmons 1991). Meissner (2017) reanalyzed the Tipu points as part of his dissertation, and discusses that Simmons was lacking a comparative collection in his initial analysis. Given this and the context of the artifacts, it is possible that some of the points could be from the Late Post-Classic.

The Second Excavation: Burials, Grave Goods, and Interment Practices

Approximately 600 individuals were recovered from inside the church and outside the structure in a cemetery around the north, west, and east walls. The vast majority were single, primary burials situated on the same east-west orientation as the church. They were interred extended on their backs with their heads facing the west and feet towards the east where the altar was located (Danforth, personal communication; Jacobi 2001). There was a burial location pattern based on sex. Jacobi (2001) found that more males were buried inside the church than females; however there was not a significantly different pattern of burials between the front and back of the church. Regardless, this suggests that males were given preference possibly due to their status or role in the church.

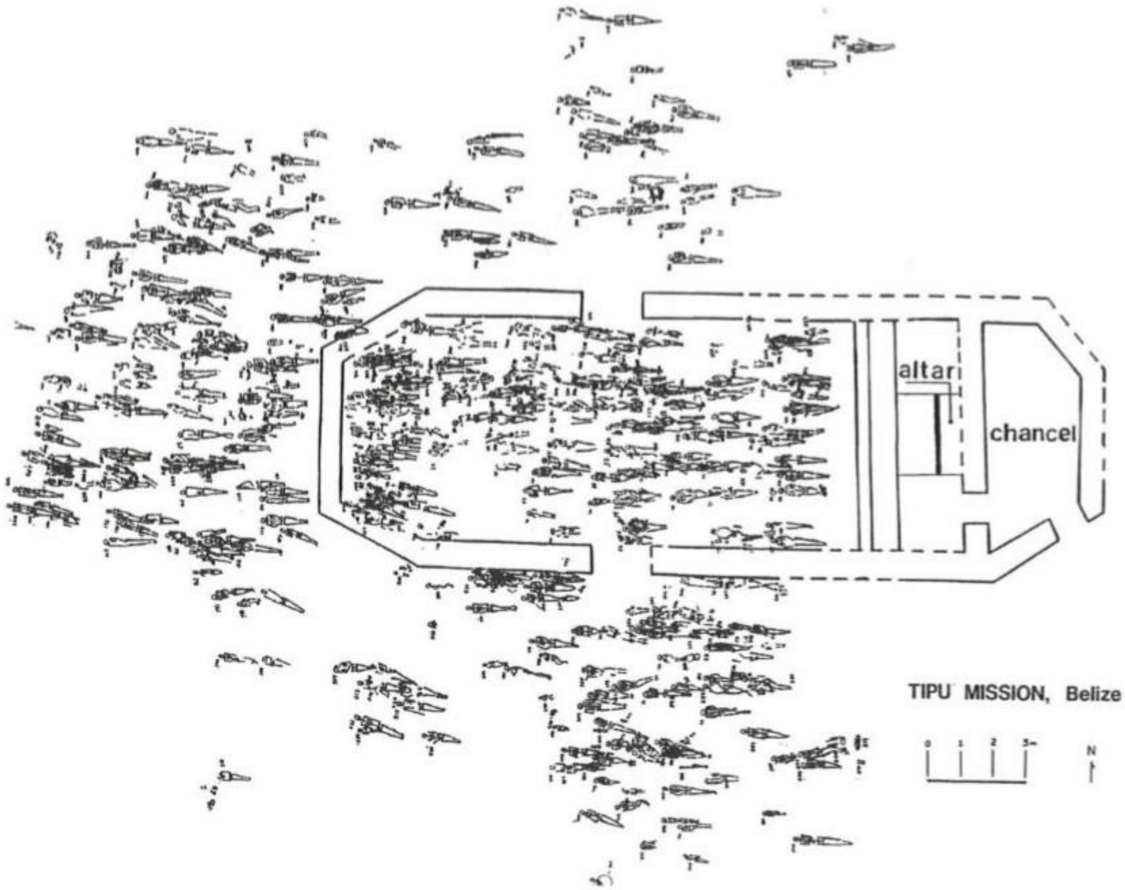

Figure 3. Map of Tipu Church and Burials. (From Cohen et al. 1997, p. 139).

Jacobi (2001) also found a pattern based on age. Of the juveniles buried in the church, only 10% were buried in the front closer to the altar and all were older than 2 years. The northern portion of the cemetery surrounding the church had the smallest number of burials but contained the highest number of juveniles. Jacobi explains that this placement could be for juveniles who were not permitted burial in other locations because they were not yet baptized (Jacobi 2001). He determined the cemetery was comprised of individuals of New World ancestry based on metric and non-metric dental traits, and that there was no evidence of genetic admixture with the Spanish. Based on stratigraphy and ethnohistory, Graham (2011) believes the cemetery was used from the time it was first built until the community was relocated in the early 18th century, and was possibly still used by a few Tipuans even after that point.

Most of the grave goods found with the colonial burials were European in nature. These artifacts included copper shroud pins, glass bead necklaces, copper bells, rings, pottery and earrings. Interestingly, there were a small number of burials with animal remains and ceramic vessels according to site files. One burial found inside the front of church included an incense burner made with Lacandon stylistic elements, but it was recovered in a Christian context (Graham et al. 1985; Graham 2011). More jewelry was encountered with burials toward the front of the church rather than the back; Jacobi (2001) attributes this to the idea that there were more children buried in the back of the church who were likely not given jewelry. More males were found with shroud pins than females and juveniles (Cohen et al. 1989; as cited by Jacobi 2001). This is could be related to male status in Christian burial preparation; however the individual buried with the incense burner was likely a female. Artifacts with interments that were more associated with the Late Post-classic included a bowl, oyster shell fragments, and a jade pendant.

The Christian practices associated with the interments played an important role in dating Tipu to the Colonial Period. Christian beliefs held that burials could only be on consecrated ground in or around the church, and those who are not baptized could not be buried there. Those closest to the altar were symbolic of being closest to God, and represented a higher socioeconomic status or role in the church (Muller-Wille 1993; Puckle 1926, as cited in Jacobi 2001). The individual had to be interred facing the east because of the belief that the body must be whole to be resurrected, so cremation was not permitted (Puckle 1926; Rutherford 1980, as cited by Jacobi 2001). Beads, crosses, or rosaries were sometimes included with the individual (Muller-Wille 1993, as cited by Jacobi 2001). Tipu was not the first Maya site to show evidence of these practices. Both Tancah and Lamanai had burials placed in an extended position in an east-west orientation, and a ring and bone beads likely from a rosary were found at Lamanai (Graham 2011; Jacobi 2001).

There were some instances where Maya and Christian ideology and practice overlapped. Both prepared the bodies by covering their deceased in cloth shrouds and included grave goods (Jacobi 2001; McKillop 2004; Sharer and Traxler 2006). Often Maya burials were oriented to the east, especially at Caracol. Some Spanish Christians and their families were buried underneath the floor where they worshiped in church (Jacobi 2001), showing that both ideologies stressed the importance of family. However, the appearance of animal bones and pottery vessels in burials at Tipu show that some aspects of the Christian practice were not adopted or outright rejected.

All of these archaeological findings are significant because they reflect how some aspects of Maya culture continued through after the Spanish came to the site. The burials are one example of traditional Maya culture that did not wholly persist through contact, especially in comparison to the continuity of their ceramic and lithic production, however they did share some common ideologies with the Spanish in some ways, and they still held on to some aspects of their own burial practices. Regardless, this gives further credibility to the idea that other aspects of Maya life, including diet, also persisted at Tipu.

Site Demography

The demographic analysis conducted by Cohen et al. (1994, 1997) shows a relatively representative population in the proportion of juveniles to adults. There were 588 recovered individuals dated to the Colonial period. This number includes 173 men, 119 women, 47 unsexed adults, and 249 juveniles were identified. Ages for juveniles were estimated by observing tooth development, epiphyseal fusion, and diaphyseal length. Ages for adults were estimated using the auricular surface of the pelvis, the pubic symphysis, dental attrition, cranial suture closure, and cemental annulation (Cohen et al. 1997).

The adult population was relatively young at death, with the majority of individuals dying between the ages of 20 and 30. Only two individuals were over the age of 50, and an underrepresentation of children between birth and 2 years old was also seen. Possible explanations for the small number of juveniles include the overall poor preservation and recovery of juveniles in the archaeological record and the practice of not burying unbaptized infants in a *visita* mission cemetery (Cohen et al. 1994, 1997). Cohen et al. (1994) specifically offered four other possible explanations for the underrepresentation of older individuals at the site. The first explanation suggests that the oldest members of the population did not adopt the Catholic practices brought by the Spanish, as they were accustomed to their original spiritual beliefs. However, Cohen et al. (1994) argues this would not be possible unless the cemetery had been used for a shorter period of time than it was. The second explanation accounts for immigration of young adults from the surrounding areas to Tipu that overwhelmed the site population. The third explanation accounted for methodological inaccuracies in the age estimation techniques. This explanation proved to be unsupported when the same techniques applied to other Maya populations found older adults to be more frequent. The final explanation argued that many died from infectious diseases that did not leave skeletal evidence, especially malaria which was widespread in the region during Spanish conquest; however, there was no mortuary evidence, such as mass burials, to suggest that there was an epidemic.

Previous Paleopathological Investigations

There have been a number of studies investigating the health patterns of the Tipu Maya that show that the population, overall, was generally healthy while facing European contact (Armstrong 1989; Cohen et al. 1989, 1994, 1997; Danforth 1989, 1991; Danforth et al. 1985; Harvey 2011; Murphy 2012). Cohen et al. (1994) calculated mean male stature at 160.3 cm, and mean female stature at 148.3 cm. Cohen et al. (1997) found that at Tipu was below average when compared to the Pre-classic and Early Classic populations at Altar de Sacrificios and Tikal, but were average or above the height of these populations during the Late Classic and Post-Classic periods. These findings suggest that stature was within typical range of the Maya and does not indicate that they suffered any severe economic deprivation (Cohen et al. 1997).

Danforth (1991) examined Harris lines, which are horizontal lines of increased bone density that represent arrests in growth during childhood (Aufderheide and Rodriguez-Martin 1998). In all, 58 femurs and 44 tibiae were assessed. Males had a higher rate of Harris lines than females, with some males showing multiple lines. She found that these lines were rare, and that children were relatively healthy (Cohen et al. 1994; Danforth 1991). Danforth and colleagues (1985) also performed analysis on femoral cortical involution. The femurs of 127 adults and 37 children under the age were sectioned at the shaft and cortical thickness was measured at different 12 points. Only 3% of adults showed evidence of osteoporosis, which was attributed to good calcium to phosphorus ratios in the diet, but the sample was also relatively young, reducing the likelihood that osteoporosis would appear. They also found that cortical bone area and femoral diaphyseal length increased with age in juveniles suggesting no severe protein-calorie malnourishment (Cohen et al. 1994, 1997; Danforth et al. 1985).

Armstrong (1989) conducted and analysis of long-bone trauma and periosteal reactions as his master's thesis project, analyzing 457 individuals. This data suggest that trauma was random and rare (8.7% of the total sample). Men had a higher prevalence (10.1%) than women (6.9%) and children. Trauma was likely accidental and not associated with political violence or rebellion activity. His study also found that periosteal reactions associated with infection were also infrequent and relatively minor. Among individuals with periosteal reactions in one or more bones males had the highest rate (22.6%), followed by females (13.8%), and juveniles (2.2%). The same pattern was found in individuals displaying systemic infection, but at a lower rate for all three groups. Osteomyelitis was identified in two individuals and was related to trauma, and there was no evidence of treponemal infection (Armstrong 1989; Cohen et al. 1994, 1997). Cohen et al. (1989) found that males buried in the front of the church had more infection than males buried elsewhere, but infection in females was most common in the back of the church. Overall, Tipu shows a low proportion of individuals with periostitis compared to other prehistoric populations (Cohen 1989; Cohen et al. 1997; Cohen, and Armelagos

1984), and likely does not reflect a population that experienced chronic illness (Cohen et al. 1997).

A number of dental studies relating to population health have also been conducted on the Tipu collection. In 1989 Danforth scored microdefects, including enamel hypoplasias, Wilson bands, and striae of Retzius, They appear in tooth enamel due non-specific metabolic stress caused by factors such as illness or starvation. She compared longitudinal sections of deciduous canines, permanent canines, and third molars from Postclassic Barton Ramie, Tikal, and Seibal, as well as Colonial Tipu to study defect interaction, age and sex patterns, temporal patterns of sociopolitical organization, and health differences between the Late Classic and Colonial Maya. In the Colonial Tipu sample children had higher rates of defects than adults, and male than females. She also found a higher rate of striae of Retzius at Tipu, suggestive of frequent, mild stress, but data did not suggest high levels of stress associated with infection or nutritional deprivation. Although the Last Classic samples showed much higher rates of growth disruption, defects, and severity, the timing of the growth disruptions were comparable to the Colonial sample (Danforth 1989).

Also looking at enamel defects, Harvey (2011) examined hypoplasias in the maxillary right central incisor and mandibular right canine of 325 individuals to evaluate childhood health patterns. She found a mean of 1.89 hypoplasias per tooth, but 91% were very slight in nature. Juveniles had a higher frequency of moderate and severe hypoplasias, while individuals who died as younger adults showed significantly more episodes than those that died as older adults. Males also had a higher frequency than females in both teeth. She compared her data to Wright's (1990) study who looked at hypoplasias at Lamanai and found that mild to moderate hypoplasias were comparable, but Lamanai had a significantly higher rate of severe episodes (6%) than Tipu (0.35%). These findings suggest that Tipu adapted more successfully to the culture change brought on by the Spanish, possibly due to their more frontier location, and had relatively good health despite European contact compared to other Colonial sites.

Murphy (2012) compared the occurrence of enamel hypoplasias and periosteal lesions to establish a possible relationship between stress and infection at Tipu. Her results did not show a significant correlation between periosteal lesions and enamel hypoplasias based on age or sex until she compared the individual bones except for a single Fisher's exact test showed a significant statistical correlation ($p= 0.0487$) between infection on the tibia and enamel hypoplasias in males; this was attributed to sampling error. Armstrong (1989) also found that the tibia was the most affected bone. Her data suggest there was not significant stress related to infection, and further supports the notion that Tipu was relatively healthy.

Cribra orbitalia and porotic hyperostosis have also been assessed in the Tipu population (Cohen et al. 1994, 1997). These pathologies are recognized as lesions on the ectocranial surface of the frontal or parietal bones (porotic hyperostosis) or the orbital roofs (cribra orbitalia). Lesions are formed when the diplöe expands and the outer table becomes reabsorbed (Aufderheide and Rodriguez-Martin 1998). For many years these lesions were attributed to anemia, but new research has shown that the more likely cause is vitamin B12 deficiency (Walker et al. 2009). Of the 214 individuals who could be scored for cribra orbitalia, 39 showed lesions. Children displayed the highest frequency at 30.5% with males (8.8%) and females (5.4%) less frequently affected. Porotic hyperostosis was observed in 304 individuals, with 16 individuals displaying active lesions and 61 with healed lesions. Again, children displayed the highest frequency of porotic hyperostosis (35.8%), followed by males (25%) and females (11.6%) (Cohen et al. 1994). Although the prevalence of anemia was relatively low compared to other Maya sites, rates were similar to those at Barton Ramie, Seibal, and Copán, but the lesions were not as severe as those found at Altar de Sacrificios. Cohen also found that there was a correlation between the shroud pins and the appearance of porotic hyperostosis (Cohen et al. 1989, as cited in Jacobi 2001), although no explanation has been offered.

Most of these data show similarities in specific disease and nutrition patterns that are key to understanding the overall health of the site inhabitants, and support the idea that Tipu was a relatively healthy population during European conquest. These studies were essential in establishing the resilience that Tipu showed in the midst of major cultural upheaval. Looking into the presence of scurvy in the population has the potential to support continuity in their subsistence practices and that Tipuans continued to stay relatively healthy throughout Spanish occupation. Further information about scurvy, including the history, clinical appearance, paleopathology, and other investigations into the disease will be discussed in the following chapter.

CHAPTER III - SCURVY

Historical Background

Scurvy is usually associated with the timeline of sailors, but according to Sauberlich (1997) the earliest descriptions of the disease may be in writings found in Mesopotamia. Other sources from all over the world also describe the disease including the Egyptian Thebes Ebers papyrus dating to 1500 B.C., writings of Susruto the Indian surgeon from 400 B.C., texts written by Hippocrates in the fifth century B.C., and Chinese writings of Chang Chi that date to 200 A.D. Other texts from Strabo, a Greek philosopher, and the Roman naturalist Pliny also make reference to scurvy (Carpenter 1986). Although there were these numerous early descriptions, Richard Hakluyt was the first to use term “scurvy” to refer to the disease in an English publication from 1589 (Sauberlich 1997).

Many of the documented cases and treatments of scurvy can be attributed to sea voyages. According to Sauberlich (1997), after a voyage to Palestine, writings by Gilbertus de Aguila from 1227 advised that sailors take ample stores of fruits and vegetables to combat the disease; however it became a predominant problem for sailors by the 15th century. Vasco de Gama and his crew were afflicted by scurvy in 1497, and were luckily able to acquire oranges from Moorish traders (Carpenter 1986). Records indicate that sailors were experiencing problems with their gums and swelling in their legs (Carpenter 1986). Ferdinand Magellan suffered a significant crew loss due to scurvy during his circumnavigation of the globe in the early 16th century. One account tells that some of the crewmembers’ gums grew over their teeth and they could no longer chew (Carpenter 1986) The French also had experience with scurvy. Jacques Cartier described an illness that had killed many of his men in 1542. He spoke of them having swollen and inflamed legs, blotched skin, and rotted gums with tooth loss (Carpenter 1986).

Many British voyages also contributed to descriptions of scurvy. Writings by Sir Richard Hawkins from an expedition in 1593 suggested that oranges and lemons were the most beneficial treatment for scurvy. The crew on a ship commanded by Sir James Lancaster became afflicted with scurvy in 1601. Records indicate that the ship stopped in St. Helena where they stocked up on lemons and oranges (Sauberlich 1997). Lancaster wrote that many men were cured with the addition of these fruit juices to their diet and a reduction in salty meat; however, 105 sailors were dead because of scurvy by the time the ship returned to England (Carpenter 1986).

Scurvy was not limited to those confined to the sea. There are numerous documented outbreaks on land, especially during times of war and famine. The great potato famine wiped out the crops in much of Europe, leaving many people to subsist mostly on maize meal. The famine itself killed over one million people, but many suffered from scurvy, especially in Ireland. Geber and Murphy (2012) analyzed individuals from Kilkenny City who were alive during the famine and found that scurvy indirectly influenced the famine-induced mortality rate, particularly in males. Another major outbreak occurred during the Crimean War in 1854-1856 in southeastern Europe. Various factors attributed to warfare caused British and French troops to be afflicted with the disease. At one point a hurricane destroyed twelve British supply ships, which contributed to a diet that lead nearly 1,600 soldiers to develop scurvy (Carpenter 1986). The French had more adequate supplies, but they did not include fresh vegetables or citrus fruits. They supplemented their diet with dandelions, but those were subsequently wiped out in the winter. By March of 1845 there were a reported 3,000 cases of scurvy followed by 1800 more in the following two months (Carpenter 1986). In North America, over 46,000 Union troops were diagnosed with the condition during the Civil War. There was also a major outbreak in Confederate troops during Sherman's march to Atlanta in 1864. Doctors were aware of the need for fruits and vegetables, but the wartime environment made it difficult to acquire and distribute these foods to troops (Sauberlich 1997) In World War I and II rationing and malnutrition were major contributors to the incidence of scurvy, particularly in India and Southeast Asia. During the First World War, 1050 cases of scurvy were reported in Indian troops in Mesopotamia during the siege of Kut-el-Amara. This was attributed to food rationing and their religious practices against eating meat. Scurvy occurred in many American prisoners of war during World War II in Southeast Asia due to malnutrition in camps (Sauberlich 1997).

Although many lives were lost on land and at sea due to scurvy, the recorded accounts over nearly four centuries contributed significantly to the medical literature. James Lind was a major contributor and is considered one of the most famous names in the history of scurvy. He joined the British Navy as a surgeon's mate in 1739 and eventually became a full surgeon in 1746 (Carpenter 1986). His crew experienced an outbreak that affected 80 men, but it was the second outbreak that led to what is known as the first controlled trial in clinical medicine. Twelve of the afflicted sailors were quarantined and fed the same diet. He came up with six different treatments and gave one of each to a set of two men over 14 days (Sauberlich 1997). He found that those who received oranges and lemons recovered in just under a week and were fit for duty after their treatment (Carpenter 1986). In 1748 he left the Navy and was awarded a full medical degree and license to practice. He then wrote his famous treatise that covered the history of the disease as well as critical reviews of the literature already written (Carpenter 1986). Armed with the knowledge of Lind, Captain James Cook embarked on three circumnavigations around the world with only a single life lost to scurvy (Carpenter 1986). He was awarded the Copley Medal of the Royal Society for this feat, but never received it because Hawaiian natives killed him on his third voyage (Carpenter 1986). Sir Gilbert Blane was a physician to the British Fleet in 1781, and eventually the household physician to the price of Wales. Blane became a significant figure in the medical community and supported the importance Lind's findings. He was awarded him the position of commissioner to the Sick and Hurt Board, and subsequently ordered a regular .75 ounce/day of lemon juice for all members of a fleet. This essentially eradicated the instance of scurvy from the British Navy, and Blane is now known as the father of naval medical science (Sauberlich 1997).

The aforementioned medical strides led to two more important findings in scurvy including a greater understanding of infantile scurvy, as well as the discovery and role of vitamin C in the disease. Infantile scurvy had previously been described in 1650, but reports of scurvy in children seemingly disappeared for another 200 years. German physicians Moeller and Kalininigrad described two children with acute rickets and one with swollen gums that was attributed to a scorbutic state, but Moeller dismissed this cause (Sauberlich 1997). A British physician, Dr. W.B. Cheadle, observed a case in 1877 of a child who was eating a diet of water and oatmeal. He made a diagnosis of both rickets and scurvy, so he ordered a diet of fresh cow's milk and finely minced raw meat, and the symptoms improved (Carpenter 1986). Another British physician, Dr. Thomas

Barlow, followed Cheadle's work and found that periosteal hemorrhage was the cause of the pain and swelling in the limbs of children with scurvy, but not in those inflicted with rickets. He described numerous symptoms of infantile scurvy in detail and continued to successfully treat the disease with cow's milk, minced meat, and citrus juice (Sauberlich 1997). German scientists who studied his work in the 1880's named the disease "Barlow's Disease" (Carpenter 1986), but during World War I it was changed to "Moller-Barlow's" disease after a group German physicians agreed it was the same disease described by Professor Moller of the University of Konigsberg (Carpenter 1986).

The connection between infantile scurvy and milk was also being explored in other countries. In the United States a report of 36 children with scurvy showed that in nearly every case they were receiving evaporated milk, suggesting that the processing of this milk might be related to the disease (Carpenter 1986). Another report was released that further attributed the disease to a dietary deficiency related to evaporated milk, but scientists were hesitant to accept this. A French doctor, Dr. Netter, argued that the illness was directly linked to sterilizing the milk, which had known antiscorbutic properties, and was not related to the development of rickets at all (Carpenter 1986). Sauberlich (1997) reports that Dr. Theodor Frolich, a Norwegian pediatrician who specialized in infantile scurvy, demonstrated that improper pasteurization of raw milk would destroy the antiscorbutic properties, which was further supported in a paper by Hess and Fish published in 1917 that showed that heating and storage before consumption also contributed to the problem (Carpenter 1986).

The connection between citrus and scurvy at sea, as well as between milk and infantile scurvy, made it clear that there was some kind of dietary deficiency happening.

However the concept of vitamins was not fully developed or understood, and the fact that humans do not produce vitamin C was not yet known. In 1840 a British doctor, George Budd, considered scurvy to be one of three diseases that could be attributed to defective nutrients, but Sauberlich (1997) explains that his research was so far ahead of its time that it received very little recognition from the scientific community. Sauberlich (1997) then discusses Casimir Funk and his vitamin theory. Funk suggested the name "vitamine" because he found that the antiberiberi factor was an amine (thiamine). He proposed four "vitamines": antiberiberi, antipellegra, antiscurvy, and antirickets, which became the basis for one of the most important studies in the history of scurvy conducted by Norwegian doctors Axel Holst and Theodor Frolich (Sauberlich 1997).

Holst's involvement in scurvy began with a study of the nutrient deficiency that caused beriberi. He was using pigeons to study the disease, but they were not producing the results he wanted, so he switched to a mammalian subject: a guinea pig. He included Theodore Frolich in the research when the guinea pig began to show symptoms of scurvy (Carpenter 1986). They developed an experiment in which 65 guinea pigs were fed an all grain diet, and they all died within about 30 days. Necropsies showed hemorrhages in the hind limbs, ribs, and the tissues inside the lower jaw, and many with loose molars. In the next set of trials the guinea pigs were fed cabbage, lemon juice, or apples, and necropsies of these subjects showed no signs of scurvy symptoms. This study led to the conclusion that the disease was produced the same way in guinea pigs and humans, and that it was caused and cured by diet (Carpenter 1986). It is important to note that these results were not duplicated in guinea pigs when two American doctors, Jackson and Moore, fed them milk as part of a study in 1916. Dr. Harriette Chick found soon after that milk was only antiscorbutic when more than 50 ml/day were consumed. Other notable findings can be attributed to McCollum and Pitz who further investigated scorbutic diets in guinea pigs that helped to narrow down the nutrient involved in scurvy is used generically.

After the identification of ascorbic acid there were various trials conducted to study scurvy in humans. In 1939 a medical student named John Crandon placed himself on a diet that included no foods that contained ascorbic acid. After three weeks his ascorbic acid levels dropped from 1 mg/100 ml to .01 mg/100 ml. By 12 weeks he developed fatigue, at 19 weeks his skin became dry and his hair follicles developed lumps on his buttocks and legs, and at 23 weeks he began to develop small hemorrhages on his lower legs. He never developed symptoms in his mouth, but he did display delayed wound healing. Another human trial took place in Sheffield, England, with volunteers who objected to military service. One group was given 70 mg/day of ascorbic acid, another was given 10 mg/day, and the last received no supplement for 26-38 weeks. After 20 weeks all of those who received no supplement showed hyperkeratotic follicles, and six had developed hemorrhages. After 36 weeks nine out of the 10 group members had swollen gums that were necrotic and bleeding. They also found that wounds made after 26 weeks did not heal normally and the prisoners had pain in their joints. Two participants experienced cardiac episodes after 36 weeks brought on by scorbutic hemorrhage, and both were removed from the study, treated with ascorbic acid, and made full recoveries. After these cardiac episodes, the remainder of the participants were treated with ascorbic acid supplements at 10mg/day. Noticeable improvements were observed after two weeks; their skin was back to normal after eight weeks, and their gums had healed after 10 weeks (Carpenter 1986).

The antiquity of scurvy kept doctors and scientists occupied for centuries, and the abundance of research led to better working conditions on seafaring ships, and, eventually, a cure to Vitamin C deficiency. Due to these early scientific breakthroughs, the modern clinical research into the role of Vitamin C has revealed many other important physiological needs for Vitamin C.

Clinical Studies

Scurvy, known clinically as hypovitaminosis C, dietary osteopenia, scorbutus, and Moller-Barlow's Disease in infants, is classified as a deficiency of ascorbic acid (generically known as vitamin C). Ascorbic acid is a water-soluble micronutrient, a six carbon alpha-ketolactone weak acid, and an antioxidant (Levine and Padayatty 2014; Vincente et al. 2011). Humans, along with guinea pigs, bats, capybaras, and some fish do not synthesize or store ascorbic acid because the gulonolactone oxidase gene is inactive, which is the essential terminal enzyme in the biosynthetic pathway of vitamin C to glucose (Levine and Padayatty 2014). Because of this inactive gene, humans must obtain ascorbic acid through dietary sources. The recommended dietary allowance for males is 90mg/day (130mg/day if a smoker), 75mg/day for women (85mg/day if pregnant, 120/day if lactating, 115mg/day if a smoker), and between 15-45mg/day for children depending on age (Levine and Padayatty 2014). Dietary sources of ascorbic acid include melon, citrus, kiwi, mango, papaya, banana, pineapple, strawberries, watermelon, asparagus, broccoli, Brussels sprouts, cabbage, cauliflower, kale, pepper, plantain, peas, potato (sweet and regular), and tomato. Grapefruit juice, orange juice, apple juice, grape juice, and cranberry juice are also adequate sources of ascorbic acid (Levine and Padayatty 2014; Thanaraj and Leon 2011). It is important to note that, according to

Vincente et al. (2011), ascorbic acid is more susceptible to degradation, and the vitamin levels in food sources can change based on growth, storage, processing, and cooking.

One of the most important functions of ascorbic acid is its role in collagen synthesis and maintenance. Collagen is a structural protein found in fibrous tissue and other tissues including ligaments, tendons, skin, dentin, hair, nails, cornea, sclera, hollow organs, blood vessels, and muscle, with the majority of bodily collagen being Type 1 collagen (Phillips and Yeowell 1997). Collagen composes a significant amount of the cartilaginous matrix, the majority of the osteoid, and a portion of dentin, making it an essential component in new bone formation, cartilage integrity, and dentin formation. It also supports the walls of blood vessels and protects them from damage and rupture. In skin, collagen maintains the skin structure and strength while also assisting in dead skin cell turnover. Ascorbic acid also plays a role in collagen development when healing wounds (Phillips and Yeowell 1997).

The high reduction potential of ascorbic acid as an electron donor serves many important physiological functions. It is a powerful antioxidant that is considered to be one of the most effective antioxidants in blood plasma and helps to eliminate free radicals in the body (Salonen et al. 1997; Woodall and Ames 1997). It reduces folic acid, which is essential in folic acid metabolism, as well as nonheme iron, which helps its absorption in the small intestine (Levine and Padayatty 2014; Tsao 1997). Salonen et al. (1997) discusses how the antioxidant mechanics of ascorbic acid may play a role in heart health, and they concluded that there is a higher risk of myocardial infarction when minimal ascorbic acid levels are not met (Salonen et al. 1997). Its reductive abilities as an antioxidant also plays a role in restoring immune function in viral and non-viral conditions linked to immunodeficiency. It can also pair with vitamin E to protect cell membranes against damage and make them more resistant to viruses (Jariwalla and Harakeh 1997). Hemila (1997) states that it is possible that ascorbic acid plays a role in the activity of the phagocyte and lymphocyte immune system cells. However, he also discusses that, while it might have an effect on cold symptoms, its role and effectiveness against preventing the common cold is still unclear (Hemila 1997).

Clinical manifestations of the scurvy can present on the skin, in the mouth, in the joints, and parts of the skeleton. In the mouth, descriptions of scurvy include spongy, bleeding gums, gingivitis, and tooth loss. The skin appears rough, dry, and scaly with "corkscrew" like hairs, and often has bruising from hematomas caused by weakened blood vessels. Patients will often complain of fatigue and painful, swollen joints or appendages. Blood work will show vitamin C blood levels of less than 300 mg (Hirschmann and Raugi 1999), which usually takes around a month of little to no dietary intake. Wound healing is diminished after vitamin C in blood reaches deficient levels, and patients can become anemic from bleeding. Scurvy is also described by abnormal osteoid and dentin formation, which affects bones and teeth, and leaves skeletal evidence of the disease that is further discussed in the next section (Crist 1998).

Paleopathology

Scurvy is recognized on the skeleton as abnormal porosity as a result of bleeding caused by weakened blood vessels and periosteal activity, which leads to the formation of scorbutic lesions on the ectocranial surface of the skull and periosteal layer of the long bones. Adults and sub-adults share the same diagnostic locations of scurvy; however, some regions of the skeleton are affected to a higher degree in sub-adults and others regions in adults (Ortner 2003). The most common appearance of scurvy is the bilateral appearance of porosity on the greater wings of the sphenoid, as this is the area associated with muscles of mastication in the skull. This porosity can often extend to the squamous portion of the temporal bone in more severe cases. Bilateral porosity on the orbital roofs is also common, but can be misinterpreted as cribra orbitalia. Walker and colleagues (2009) suggest that bone marrow hypertrophy caused by B12 deficiency or orbital roof hematomas due to vitamin C deficiency can cause the lesions associated with cribra orbitalia. Other cranial areas that can develop abnormal porosities caused by scurvy include the cranial vault, the maxillary process of the zygomatic bone, the zygomatic arch of the temporal bone, and the area around the infraorbital foramina (Ortner and Ericksen 1997).

The bones of the mouth region are also often affected due to bleeding caused by the deficiency. These symptoms are more commonly found in adults than in sub-adults, and seen in the palate, the posterior maxilla, and the medial surface of the coronoid process of the mandible (Ortner 2003). Gum recession causes the alveolar bone around the teeth to degrade and recede, and results in porosities between the alveolar spaces (Ortner, Kimmerle, and Diez 1999). Bleeding in the gums and the surrounding gum structure is worsened by the mechanics of chewing (Ortner et al. 2001). Antemortem tooth loss is the most severe result of scurvy in the mouth. This can also cause the roots of the teeth to become blackened as blood flow is cut off when the alveolar bone degrades and the tooth falls out (Saul 1972). The inflammatory response and the reduced collagen production caused by scurvy may contribute to the exfoliation of the teeth (Ortner et al. 2001).

Postcranial appearances of scurvy can be seen on the supraspinous and infraspinous fossae of the scapulae, the ribs near to the osteochondral joint, and the metaphyses of the long bones. Scorbutic lesions in the scapula tend to be rare in children; they seem to have more activity in the ribs than adults. Sub-adults, however, suffer from scorbutic lesions in the long bones much more often than adults due to new bone growth and trauma caused by locomotion when sub-adults have not learned to walk (Ortner 2001). Among adults, long bone lesions that resemble scorbutic lesions are more likely to have been caused by trauma, but the joints in older individuals can also be affected due to arthritic and osteoporotic bone changes caused by aging. Ortner (2003) suggests that lesions on the long bones might occur as spicules rising form the cortex due to the metaphyseal areas only partially stripping the periosteum with some areas still connected to the bone.

Differential Diagnosis

There are several skeletal pathologies that can be misinterpreted as scurvy. Cribra orbitalia and porotic hyperostosis are among the most problematic. Porotic hyperostosis usually presents as porous lesions on the cranial vault, while cribra orbitalia appears as porosities on the upper eye orbits. These porosities are the results of bone marrow hypertrophy caused by anemia, though work by Walker et al. (2009) suggests B-12 deficiency as a likely cause. These pathologies are often mistaken for scurvy, as the lesions associated with these pathologies are nearly identical on a macroscopic level and appear in similar areas of the skull. However, the lesions associated with cribra orbitalia and porotic hyperostosis are caused by marrow hypertrophy, while hemorrhaging causes the lesions associated with scurvy (Aufderheide and Rodriguez-Martin 1998).

Klaus (2015) recently discussed the importance of distinguishing between these two different lesions. He uses a visual differential diagnosis rubric to ascertain if the abnormal pathologies are consistent with various conditions, and finds that scurvy is the most likely cause. While he stresses the importance of consistency and precision in describing scurvy, he also makes it clear that this rubric should not be used as a checklist (Klaus 2015). In another paper, Klaus (2014) also argues that the presence of these pathologies can make the diagnosis difficult because of the role vitamin C plays in the absorption of non-heme iron. A deficiency in vitamin C can cause anemia; thus the appearance of lesions on the ectocranial surface or the upper orbits can be complicated.

Rickets is classified as a vitamin D deficiency, and is essential in maintaining blood calcium and phosphorus levels needed to mineralize bone (Aufderheide and Rodriguez-Martin 1998). One of the most identifiable symptoms of rickets is bowing of the leg bones. Both rickets and scurvy can cause widened metaphyses of the long bones and knobby costrochondral rib junctions; however different processes cause these symptoms (Aufderheide and Rodriguez-Martin 1998). Rickets can also produce porous lesions on the skull similar to those in scurvy, cribra orbitalia, and porotic hyperostosis, but the porosity is generally much finer in rickets and does not exhibit marrow hypertrophy like porotic hyperostosis and cribra orbitalia (Klaus 2015; Ornter 2003). Buckley et al. (2014) states that the lack of mineralization in rickets causes the lesions to form a spiculated appearance with large pores where osteoid would have been deposited. The sphenoid is also not affected by the pathogenesis of rickets (Klaus 2015).

Meningitis is the inflammation of the meninges, the membranes around the brain. Bacteria, viruses, fungi, amoebae, parasites, or diseases such as cancer and lupus, as well as drugs or trauma can result in meningitis (CDC). This inflammation can cause lesions located on the endocrinal surface of the cranial vault. Trauma to weakened meninges caused by low vitamin C levels can cause slow hemorrhaging between the skull and brain, resulting in porotic formation on the endocranial surface of the skull. However, the majority of the literature concerning the manifestation of scurvy on the skeleton does not discuss endocranial lesions as a marker. It is possible that scurvy is a cause of this meningeal reaction, but meningitis can also be caused by tuberculosis, syphilis, tumors, and subdural hematomas, and these diseases may cause lesions that are not necessarily identical in form (Lewis 2004). Great care should be taken to assess the appearance of endocranial lesions and to look for other pathological markers on the skeleton to ascertain which disease is the cause.

Leukemia is the cancer of blood forming cells (myeloid and lymphoid hematopoietic cells of the bone marrow). This causes the formation and circulation of abnormal blood cells, most often leukocytes, which replace the normal bone marrow (Cancer.org; Ortner 2003). Ortner states that the most common bone change associated with leukemia is a narrow radiolucent lesion on the metaphyseal side of the growth plate, and it can resemble lesions found in scurvy in the same area (Ortner 2003). Halcrow and colleagues (2014) identified lesions in resembling leukemia in the crania of a juvenile, but found the porosities were much larger compared to those in the juvenile, and that the lesion locations were not consistent with scurvy.

Aufderheide and Rodriguez-Martin (1998) describe hypertrophic osteoarthropathy as the symmetrical formation of new bone on the diaphysis of tubular bones along with peripheral arthritis, and Ortner (2004) describes it as symmetrical diaphyseal periostitis on the smaller long bones and other tubular bones. The condition is often associated with different types of cancer, usually lung cancer. Some evidence shows that increased peripheral blood flow might be the cause, another hypothesis suggests that it invokes a toxic substance created by the primary lesion, and one other theory suggests that a neurocirculatory mechanism associated with forms of pulmonary inflammation and cancers stimulates the osteoblasts to produce the pathology, but the etiology is still unknown (Golding 1984, as reported by Aufderheide and Rodriguez-Martin 1998; Jaffe 1972; Klaus 2014; Orter 2003) Other symptoms of this disease cause symmetric lesions and the clubbing of the fingers and toes (Aufderheide and Rodriguez-Martin 1998). The condition is expressed by the presence of periostitis and lumpy new bone formation. Due to this lumpy morphology, it is less likely to be mistaken for scurvy; however it still should be considered.

Infantile cortical hyperostosis, also known as Caffey's disease, is characterized as localized, tender lumps of subperiosteal new bone formation on the rib, mandible, long bone diaphyses, and clavicle. This disease is rare, and usually only affects children age one year or younger. Klaus (2014) states that the condition has a tendency to produces asymmetrical, unilateral lesions on the mandible, ribs, and metatarsals. This is potentially problematic if only one side of the element is available to score, as lesions that appear in similar areas caused by scurvy are bilateral, but the presence or absence of other diagnostics can narrow down the condition.

Yaws was considered by Buckley et al. (2014) in the differential diagnosis in a Lapita skeletal sample from the Pacific Islands. Yaws is a form of treponematosis caused by *Treponema pertunue*, and is often associated with tropical indigenous populations

(Aufderheide and Rodriguez-Martin 1998; Ortner 2003). The disease is contagious and can be spread when contact is made with open lesions containing the spirochetes. Lesions form on the skin in the first stage of the disease, and bone may start to be affected by periostitis during the secondary stage. More serious skeletal reactions occur during the tertiary phase that occurs five to ten years after the initial infection (Aufderheide and Rodriguez-Martin 1998). As in scurvy, swelling in the joints is a clinical symptom of yaws. Yaws can be differentiated because the associated lesions are gummatous, and it can often cause dactylitis in younger individuals.

Various other infections (specific and nonspecific) and trauma are also potential differential diagnostics. Osteomyelitis is defined as the inflammation of bone and bone marrow. Ninety percent of the time the inflammation is caused by the pus-producing bacteria *Staphylococcus aures* (Aegerter and Kirkpatrick 1975; Blockey 1984, as reported by Aufderheide and Rodriguez-Martin 1998; Morse 1978). The pathology appears as bone destruction and new bone formation. The affected bone surface shows pitting and cavities that can be mistaken for the porosities associated with scurvy. Periostitis is the inflammation of the periosteum and results in many situations of trauma and infection. It can resemble the lesions in the long bones associated with scurvy, so care should be taken to identify the cause of periostitis. Any type of trauma or activity that results in subperiosteal hemorrhaging can also result in the formation of lesions that are associated with scurvy. Those traumas can be distinguished from scurvy by the location of lesion, bilateral symmetry, and the presence or absence of other symptoms of scurvy.

Given the range of pathological possibilities, one of the most difficult problems in the study of scurvy continues to be the identification of the pathology itself. Although some of the possibilities can be eliminated during the differential diagnosis process, other pathologies, especially cribra orbitalia and porotic hyperostosis, are still difficult to discern from scurvy on the macroscopic level. In addition, these conditions can co-occur, furthering the challenge in identifying the lesions.

Scurvy in Tropical Populations

The thought of scurvy occurring in a tropical environment may seem improbable due to the presence of many local sources of the vitamin, but there are numerous cultural and environmental factors to consider. Thus, an investigation into the instance of scurvy in tropical populations is necessary. Although industrialization has helped to decrease the occurrence of nutrient deficiencies in modern populations, this is not true for every part of the world, especially those in third world or underdeveloped countries. Additionally, other bioarchaeological studies of scurvy in tropical populations have been conducted that also need to be considered.

Scurvy in Modern Populations

The instance of scurvy, especially on a large scale, is rare in the modern world after the cause of scurvy was finally discovered. With the help of Sir Gilbert Blane, Lind's studies in the 1700's on the curative properties of citrus helped to eradicate scurvy in the British Navy (Carpenter 1986). After ascorbic acid was identified and synthesized in 1933, it went into mass production for agricultural, industrial, pharmaceutical, and nutritional use. No studies about vitamin C deficiencies in modern Central American cultures were found after a thorough search of the existing literature. However, there were studies from other parts of the world that have ecologically comparable ecosystems.

Villalpando et al. (2003) studied the sociodemographic and dietary factors that contributed to vitamin A, vitamin C, and folic acid deficiencies in children and adults in Mexico. Blood samples and dietary data were taken from a sample that included children under the age of 12, and females between the ages of 12 and 49. In children, they found that the likelihood of having a vitamin C deficiency decreased as socioeconomic status increased. The same held true for women, but there was no difference found between those living in urban and rural areas. Overall, 30% of children and 40% of women were vitamin C deficient. These results were consistent with the reported dietary data that showed fruits and vegetables were ranked low on the list of foods most frequently consumed, with consumption of less than 5 g/day. The authors suggest that the lower vitamin C levels in children of lower socioeconomic status could be attributed to the cultural exclusion of or high cost of these foods.

Ravindran et al. (2011) conducted a survey of adults over age 60 in two regions of north and south India that asked respondents about their tobacco use, alcohol consumption, cooking fuel use, diet, and socioeconomic status. They conducted anthropomorphic measurements and blood testing to measure vitamin C levels. Of the respondents who were able to provide blood with measurable amounts of daily dietary vitamin C intake, 74% in the northern region and 46% in the southern region showed deficiencies, with sub-optimal levels measured in 15% of the northern population and 28% in the southern population. The authors suggest that the high level of oxidative stress from smoking tobacco likely causes a high turnover rate of ascorbic acid. They also state that the smoke produced by the combustion from cooking with biomass fuels contains carbon monoxide, nitrogen formaldehyde, and polyaromic hydrocarbons, and shares many of the same elements of tobacco smoke, suggesting that the similar elements in both types of smoke are likely causing oxidative stress contributing to the high ascorbate turnover. Seasonal factors between the northern and southern regions, specifically monsoon patterns, also played a role in the availability of vitamin C rich foods between the two populations. Finally, they found that the deficiency was more prevalent in men, and that socioeconomic status was a contributing factor.

Khan and Iqbal (2006) identified the extent and prevalence of vitamin C deficiency in South Asian populations, particularly Pakistan, as well as how it compares to Western populations. This study corroborated other research that suggests males and smokers have a higher rate of vitamin C deficiency, but they also concluded the same in drug abusers, individuals who have been infected with parasites or *H. pylori* bacteria, or those with low HDL cholesterol levels. Researchers also identified a seasonal pattern of higher vitamin C plasma levels in winter due to the availability of more fruits compared to summer. The deficiency was highest amongst Indians and other South Asian populations compared to the Western populations except for Mexico. This was attributed to the cooking method and lower intake of vitamin C rich foods.

In summary, these studies show causes of vitamin C deficiencies in modern populations from tropical environments that could be linked to the same issues that may have confronted the Tipu inhabitants. While these environments easily facilitate the growth of vitamin C rich foods, social inequalities can limit the access of certain foods for lower level socioeconomic groups. Further, seasonal factors can also contribute to the growth and vitality of these foods. Cooking methods were also cited as a potential cause, and is further supported by Igwemmar et al. (2013), which found that excessive heat, water, and air exposure played a significant role in reducing the vitamin C content of foods. Amongst other cultural and biological causes, these factors open up the possibility that scurvy was experienced to some degree by the Tipu population, and warrants further investigation into the pathological markers.

Scurvy in Past Populations

Halcrow and colleagues (Halcrow, Harris, Beavan, and Buckley 2014) found the first probable bioarchaeological evidence of scurvy in Asia. A skull from a six year old was recovered from a jar burial at the site of Phnom Khnang Peung in southwest Cambodia dating to the 15^{th}-17^{th} centuries. The skull had vascular impressions on the ectocranial surface of the frontal bone and the alveolar bone of the maxilla. Abnormal porosity was found on both greater wings of the sphenoid, as well as the hard palate. Cribra orbitalia was present bilaterally; however this was attributed to bone marrow hyperplasia and not scurvy. Halcrow et al. (2014) discuss four variables that contribute to scurvy: reduced intake of vitamin C, increased requirements for vitamin C, malabsorption of vitamin C, and genetic predisposition to low vitamin C levels. They explain that factors such a low socioeconomic factors or cooking can contribute to a deficiency, but also suggest poor dental health that prevents chewing of tough foods, and inhospitable environments, such as mountains and colder climates, that restrict the procurement of foods with vitamin C. Other factors can increase the requirements for vitamin C including infection, injury, burns, pancreatitis, anemia, rheumatoid arthritis, and diabetes. Malabsorption can be attributed to diseases in the gastrointestinal tract including

Whipple's disease, celiac disease, Crohn's disease, and cancer patients with diarrhea and vomiting. The haptoglobin polymorphism can also contribute to scurvy. The Hp 2-2 polymorphism is associated with lowered ascorbic acid levels in males (Delanghe et al. 2007, 2011; Na et al. 2006, as reported by Halcrow et al. 2014), and that the associated Hp 2 allele is thought to have originated in Southeast Asia (Langlois and Delanghe 1996, as reported by Halcrow et al. 2014).

Buckley and colleagues (2014) also found scurvy in a tropical population from Teouma, Vanuatu, Pacific Islands. The recovered individuals are associated with a time during the Neolithic period where the Lapita was colonizing the area. The sample was observed for the presence or absence of abnormal porosity and subperiosteal new bone deposition. The resulting sample size was 93 with 15 being sub-adults. There were five sub-adults with evidence of scurvy both cranially and post-cranially. Twenty-five adults showed signs of subperiosteal new bone formation. Only seven adult crania were recovered from the site, but two of them had abnormal porosities that were associated with scurvy. Buckley discusses a few possibilities as to why this population suffered from the deficiency. The Lapita introduced many crops and livestock to the area, but it is unclear how well the crops flourished, especially during the beginning of colonization, and it is likely they depended on local resources. Although some of the naturally occurring plants are good sources of vitamin C, cooking significantly reduces the vitamin content. The same can be said about some of the staple root tubers that were cultivated, although it could take anywhere between six months to a few years to grow a supply substantial enough to support the population. Faunal analysis revealed that the Lapita were consuming marine and land species that were high in protein, but low in vitamin C.

They also discussed that the damage caused by seasonal droughts and cyclones could also affect the abundance of vitamin C rich vegetation.

Populations in Peru have also been found to have symptoms of scurvy. Ortner and colleagues (1999) looked at scurvy in a Peruvian sample housed at the National Museum of Natural History in Washington D.C. The greater wings of the sphenoid were observed for the presence or absence of abnormal porosity. Of the 36 sub-adults who were diagnosed with scurvy, the older individuals had more cases, and 35 had the lesions bilaterally. Klaus (2014) investigated the instance of scurvy in 641 late pre-Hispanic and Colonial period sub-adults recovered from the Lambayeque Valley in Peru. Klaus hypothesized that scurvy would be common in the population, and cases would increase after Spanish contact. In the entire sample there were five cases that were positively identified and described as scurvy, two cases from the pre-Hispanic period and three from the Colonial period.

White et al. (2006) studied the combined effects of diet, culture, disease, and ecology at Marco Gonzalez and San Pedro, Post-classic and Classic Maya sites on the coast of Belize. Analysis consisted of observation of cranial lesions associated with porotic hyperostosis, cribra orbitalia, scurvy, and linear enamel hypoplasias, as well as carbon and nitrogen isotope evaluation. They found that lower trophic levels of dietary protein were associated with anemia, and that the higher levels associated with carnivory values were correlated with scurvy. However, the authors did not believe that scurvy can be attributed to a single factor of malnutrition or disease. Instead, they suggested further exploration into the synergistic effects of prolonged breastfeeding, vitamin C deficiency, infection, anemia, and the environment. Ethnohistoric accounts by the Spanish that indicate the poor health of the Maya are consistent with these findings, but the authors note the Maya people had to survive long enough for the lesions to appear.

Wrobel (2014) assessed the remains of a “late adolescent” that were recovered from the rock shelter entrance of Actun Uayazba Kab in Belize. Evidence of scurvy on this individual was found on the posterior maxilla, pinprick lesions on both greater wings of the sphenoid and temporal bones, lesions on the palate, lesions on the internal and external surface of the zygomatic, lesions on the popliteal surfaces of the femora, porotic hyperostosis on the midline of the parietals and occipital, cribra orbitalia, and periodontal disease. He discusses three possible explanations for the occurrence of scurvy in Maya populations. Cultural constraints on the diet may play a role despite the abundance of vitamin C rich foods in the region. This could include a preference for consuming maize, which is low in vitamin C (Ortner et al. 2001, as reported by Wrobel 2014). Heat from cooking, as well as prolonged storage or preferential consumption during certain stages of maturation, can reduce or destroy the vitamin C content of food. Wrobel further discusses that it is also possible that seasonal factors affecting the availability of vitamin C rich foods can contribute to the deficiency, citing a study by Behie and Pavelka (2005) which found that howler monkeys in Belize changed their diets after a recent hurricane wiped out the forests of fruit. Lastly, disruptions in the metabolism and uptake of vitamin C, such as *H. pylori* infection and parasites, can also diminish vitamin C levels (Wrobel 2014).

In 1972 Saul was the first to argue for the occurrence of scurvy in the Maya, as part of an evaluation of the human remains found at the pre-classic Maya site of Altar de Sacrificios in Guatemala. His criterion for identifying scurvy was the co-occurrence of periodontal degeneration and subperiosteal hemorrhaging caused by weakened blood vessels. Periodontal degeneration was found in 45 individuals, subperiosteal hemorrhaging in 17 individuals, and they co-occurred in 15. He noted that the idea of scurvy in a tropical area seemed unlikely, but offered several explanations for its appearance. He discussed that the Maya today eat very little fruit compared to American populations. Although fruits and vegetables with vitamin C are available throughout the year, they are not constantly consumed, and storage, processing and cooking of these foods drastically diminishes the vitamin C content. In addition, these vitamin C rich foods were likely traded rather than consumed by the growers in prehistoric times.

In 1987 Cohen evaluated the Tipu collection for scurvy using Saul's diagnostic criteria, but interpreted them as the correlation of "antemortem tooth loss and periosteal reactions (along with other symptoms of the disease including porotic hyperostosis)" (Cohen 1987, p. 85). He found that the correlation of antemortem tooth loss and periosteal reactions happened no more frequently than what would be expected by chance, which to him indicated that the two conditions were not part of the same disease. However, Saul's hypothesis defines periodontal degeneration as various degrees of breakdown of the bony alveolus or tooth socket region. In contrast, Cohen's interpretation of Saul's definition as antemortem tooth loss implies that individuals who showed signs of bone degeneration without tooth loss were not included. Taking this into consideration, analysis using Saul's more specific criteria could change the interpretation of scurvy in the Tipu population.

It is evident in these reviewed studies that the occurrence of scurvy in the Tipu population is not out of the realm of possibility. Environmental factors, such as hurricanes, as well as cultural practices, such as cooking, are probable contributing factors that are applicable to Tipu. Other tropical populations, both past and present, have also experienced scurvy. Additionally, since the initial health studies conducted on the population, new information about scurvy and the paleopathology of the disease has been published. This evidence is enough to further investigate the possibility that the Tipu people could have suffered from a vitamin C deficiency.

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CHAPTER IV – MATERIALS AND METHODS

The Sample and Data Collection

The approximately 550 individuals recovered from Tipu were the focus of this data collection. This project evaluated all available crania that were at least 50% complete, including those from sub-adults. The final sample size was 143 individuals. This included 75 adult males and 43 adult males. By age, 7 were 0-5 years, 18 were 6-14 years, 87 were 15-29 years, and 31 were 30+ years.

The greater wings of the sphenoid and the squamous portion of the temporal bones were observed for scorbutic lesions. The maxilla and mandible were also evaluated for several markers. No defined data scoring standards exist for scurvy. Therefore, the data collection method used in this project was developed based on scoring standards from Ortner and colleagues (1999), taking into account the fluid appearance of scorbutic lesions.

Porosities on the sphenoid and temporal bone were scored as follows: 0- Absent; 1- Porosity present but barely discernable; 2- Porosity present and easily discernable, but no clear lesion area is defined; 3- Porosity present with increasing number of foramina number and size; a lesion area is discernable, but may be subtle or small; 4- Severe porosity with large foramina; a lesion area is clear and may affect the entire element; 9- Element not available for scoring. Examples of each of the scoring options (excluding level 4 due to the absence of this severity in the population) are given in Figures 4 – 7.

Figure 4. Porosities with Score of 0

Figure 5. Porosities with Score of 1

Figure 6. Porosities with Score of 2

Figure 7. Porosities with Score of 3

Periodontal disease was scored as 0 – absent or 1 - present-1 for alveolar porosity, alveolar recession, and antemortem tooth loss because of the probable association of periodontal disease with scurvy. Examples of each condition are given in Figures 8 – 10.

Figure 8. Alveolar Porosity

Figure 9. Alveolar Recession

Figure 10. Antemortem Tooth Loss

Data Analysis

The frequency of the appearance of lesions on each of the skeletal elements that are being measured was calculated, and comparisons were made on the population level as a whole, by sex, and age. The frequency of lesions on the temporal and sphenoid was determined, as well as the co-occurrence of lesions on both elements. The co-occurrence of lesions on the temporal and sphenoid bones as well as with presence of periodontal disease as indicated by alveolar recession, alveolar porosity, and antemortem tooth loss on the mandible and maxilla was also calculated. Chi square tests were used for all statistical testing.

Hypotheses Tested

There were several hypotheses addressed in this project. The first set concerned the demographic distribution of the condition:

- It was expected that scurvy would be present in the Tipu population, but at generally low levels.
- It was expected that juveniles would display a higher rate of scurvy than adults, but there would be no significant difference between males and females.

The second set concerned the expression of scurvy on the skeleton:

- It was expected that the appearance of scurvy would be most distinguishable and frequent on the greater wings of the sphenoid.
- It was expected that it would occur next most frequently on the squamous of the temporal bone.
- It was expected that most individuals would have lesions on both elements.

The final set concerned co-occurrence of cranial vault and periodontal disease:

- It was expected that porosities on the sphenoid and temporal would should a high level of co-occurrence with alveolar degeneration as well as antemortem tooth loss.

Examination of these hypotheses would help reveal possible patterns of scurvy at Tipu as well as shed light on possible cultural practices that might be associated with its presence.

CHAPTER V – RESULTS AND DISCUSSION

Initial Results

As may be seen in Table 1 below, very few of the 143 individuals scored had lesions with a severity score of 3 or 4. In contrast, a larger number had lesions that were scored as level 1. However, the slightness of these porosities often made them difficult to distinguish from level 0. Furthermore, other conditions may also be causing the porosities (Powell 1999, p. 147), such as attachment sites for Sharpey's fibers. Therefore it was chosen to separate the sample into two groups: those unlikely to have scurvy, and those who possibly have scurvy. Individuals who scored a 0 or 1 for lesions on the squamous portion of the temporal bone and/or the greater wing of the sphenoid were considered unlikely to have scurvy. In turn, individuals who scored a 2 or above for scorbutic lesions on one or both of the aforementioned cranial elements were considered to have possible cases of scurvy, and will be referred to as having "scurvy" in this chapter. The scores of 2 or above were collapsed because this project was not investigating the various levels of scurvy but rather it focused on just the presence of the condition.

	Temporal Lesion Severity					**Sphenoid Lesion Severity**				
	0	**1**	**2**	**3**	**4**	**0**	**1**	**2**	**3**	**4**
Age (years)										
0-5	2	5	1	0	0	1	2	1	1	0
6-15	3	10	4	1	0	0	7	4	0	0
16-29	22	46	14	3	0	11	27	15	6	0
30+	11	16	4	0	0	3	12	3	1	0
Sex										
Males	17	41	13	2	0	7	24	12	6	0
Females	16	21	4	1	0	7	13	6	1	0

Table 1 *Initial Patterns of Lesion Severity by Age and Sex.*

General Demographic Patterns

This section discusses the pattern of scurvy based on sex and age. Only adults were considered in the sex analysis. Lesions were scored if they were present on either the greater wings of the sphenoid, the squamous portion of the temporal bone, or there was a co-occurrence of lesions on both cranial elements.

Sex

Figure 11 shows the prevalence of scurvy for males and females. Males had a higher prevalence of scurvy at 29.3% than females with 20.93%. However, a chi square test suggests that there was no significant difference (X^2= .9963, p= .318196).

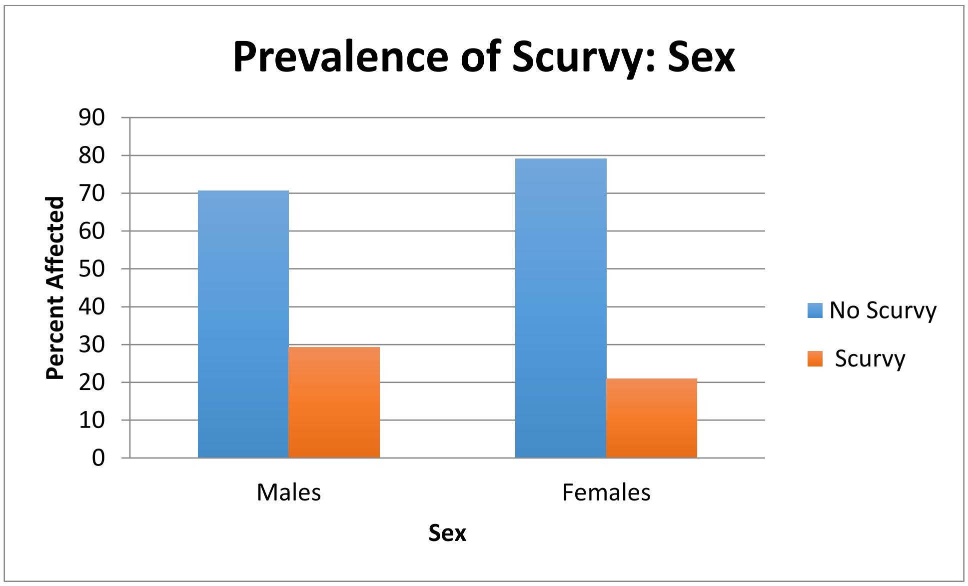

Figure 11. Prevalence of Scurvy by Sex

In one of the few studies that looks at sex-specific rates of scurvy, an investigation conducted by Buckley and colleagues (2014) of the Lapita from the Pacific Islands found a similar pattern in which adult males had a slightly higher prevalence of scurvy. Seven males and five females were determined to have probable scurvy, while four males and five females were determined to have possible scurvy. The authors explained that although the Lapita had access to foods high in vitamin C, such as coconut, yam, and wild edible leafy greens, certain cultural practices, such as heavy exploitation of coconuts and steaming of the leafy greens, may have reduced the accessibility or vitamin C content of these sources. Although the Tipuans also lived in a tropical environment, similar food preparation methods could explain the appearance of vitamin C deficiency in this sample.

Evidence of males experiencing more nutrition challenges compared to females is seen in a number of other markers at Tipu. In the initial assessment of cribra orbitalia by Cohen (1997), an indicator of anemia, men had a rate of 8.8% compared to the 5.4% in women for severe remodeled lesions. Cohen et al. (1994) discusses the rates of porotic hyperostosis, another anemia marker, between the sexes. They found that men were more commonly affected (25%) than women (11.6%), and the results were statistically significant. Taking these nutritional differences into consideration are important, as nutritional deficiencies usually are not isolated but rather act synergistically. Furthermore, nutritional status has been closely tied to immunological strength (Beisel 1996). Previous health studies at Tipu based on sex similarly show males expressing higher levels of for a wide range of health conditions, including infection (Armstrong 1989), linear enamel hypoplasias (Cohen 1989) and Harris lines (Danforth 1991).

Age

Figure 12 shows the prevalence of scurvy based on age. When considered as two composite groups, 28% of sub-adults had lesions that were indicative of scurvy, while 26.3% of adults were affected. As would be expected, with such a small difference, a chi square test comparing sub adult and adult rates suggests that there was no significant difference (X^2= 0.3413, p=0.559056).

Figure 13 breaks down the appearance of scurvy in each age group. Of the four groups, sub-adults between the ages of 16 and 29 had the highest percentage of lesions indicative of scurvy. The chi square test comparing all age groups found that there was no significant difference (X^2= 2.5795, p=.461099).

In their study of Post-classic and Historic Maya from the Marco Gonzalez and San Pedro sites on the coast of Belize, White and her fellow researchers (2006) found a high percentage of sub-adult scurvy at 58%, although they do not break it down further by age. They suggest weanling diarrhea as a contributing factor to the deficiency, but also consider parasitic infection from the marine based diet of her sample. Marine resources were not as abundantly consumed at Tipu (Jacobi 2001), however, reducing the likelihood of parasitic infection, and may explain the fact that the rate of scurvy among juveniles was half that found at Lamanai. Of course, young children at the site could not have avoided weaning and its health consequences.

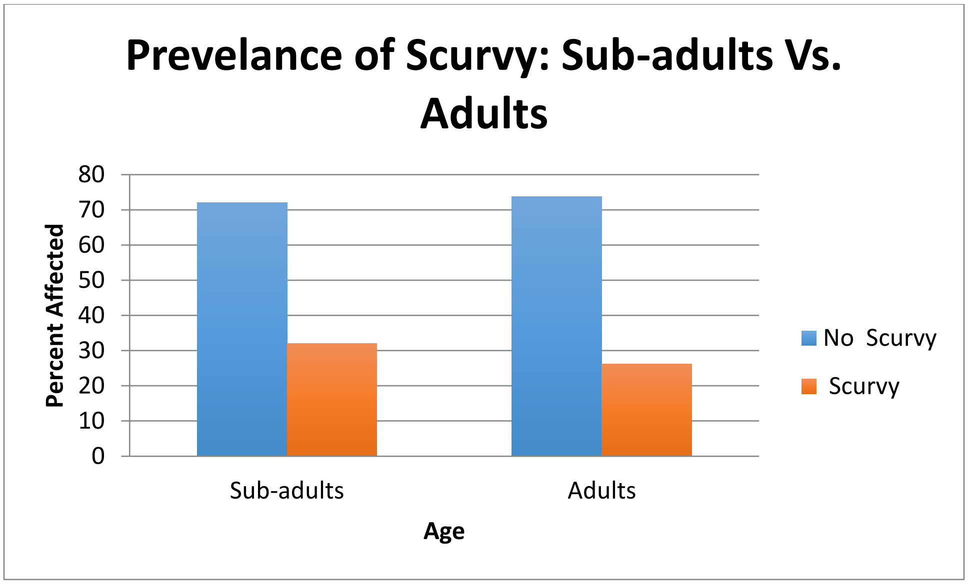

Figure 12. Prevalence of Scurvy: Sub-adults vs. Adults

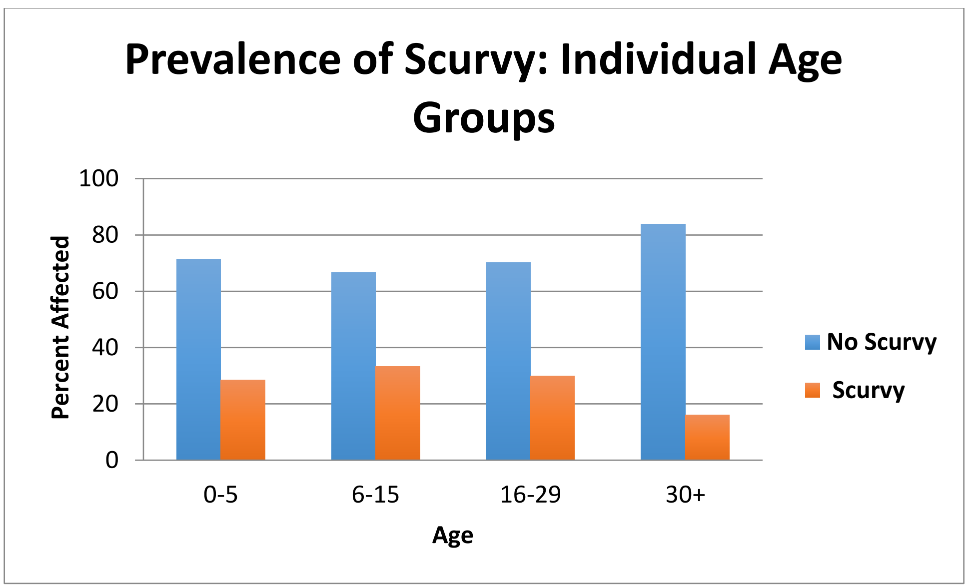

Figure 13. Prevalence of Scurvy: Individual Age Groups

The hypothesis that juveniles would have higher rates of scurvy than adults was not supported since the rates are essentially the same. However, the expectation of higher rates in juveniles may not necessarily be ubiquitous. In the one other study found that reported prevalence in both sub-adults and adults, Buckley et al. (2014) notes that adults had a slightly higher level of scurvy among the Lapita from the Pacific Islands. This pattern is likely attributed to the dietary patterns during the colonization of Polynesia. There is evidence that the Lapita had access to coconuts, but were possibly heavily harvested during the transition, and regrowth was slow. It is also suggested that waiting for the cultivation of new crops to be abundant for subsistence played a role. Even when these transplanted crops, such as yams, which are high in vitamin C, were consumed, cooking and storage practices depleted the vitamin C content. Such an explanation cannot explain the patterns seen at Tipu, as they do not appear to have been undergoing a significant transition in subsistence even with Spanish contact (Klaus 2014; Ortner et al. 1999; Saul 1972); furthermore, any change would have affected the entire population, not just sub-adults. However, there are potentially cultural similarities in that cooking and storage methods at either site would greatly reduce the vitamin C content in food they were consuming.

In a consideration of scurvy rates among children by age, sub-adults between 6 and 15 years old had a somewhat higher prevalence of scurvy (33.33%) compared to those between the ages of 0 and 5 (28.57%). Although the chi square test showed the difference was not significant (X^2= 0.0016, p= .968346), this finding was not expected given the strong contributory role that weaning has been given in causing scurvy (White et al. 2006). As well, Klaus (2014) observed in his investigation of 641 sub-adults from the Lambayeque Valley in Peru only five sub-adults that showed convincing cases of scurvy, four of whom were under the age of 5. However, it does concur with a pattern Ortner and colleagues (1999) found in their Peruvian sample of 363 sub-adults. Sub-adults between the ages of 7-12 and 13-18 had a higher prevalence of scurvy than those between birth and 6 years. It was expected that the distribution would be greater in the youngest sub-adults, but the sample likely reflects a bias towards older sub-adults due to preservation when the samples were recovered.

This factor may also be in operation at Tipu for which most previous research suggests a generally healthy juvenile cohort. Danforth (1989) did find that sub-adults with growth disruptions directly after birth were less likely to survive the weaning period, but in contrast, in Cohen's (1989) evaluation of porotic hyperostosis in children, he found that older children (9 or older, 40.5%) had a higher rate of affliction that those younger (younger than 9, 11.6%). However, Armstrong (1989) reports that periosteal reactions were rare, and seen in only around 2% of sub-adults with systemic infections even less common (1.1%). Danforth (1989) studied enamel defects in the population and concluded that Tipu did not experience high levels of prenatal stress, maternal malnutrition, or infection associated with severe malnutrition. Another study by Danforth, Bennett et al. (1985) observed that cortical bone area and femoral diaphysis length in sub-adults increased regularly with age, indicating that there was not a severe protein-calorie deficiency generally occurring in the diet. These patterns were more reflective of an overall healthy population, and may suggest why Tipu had such a lower rate of scurvy than did Lamanai.

Among adults, individuals between the ages of 16 and 29 showed a similar level of scurvy (29.89%) to that seen in sub-adults, but those over the age of 30 had about half the rate (16.13%). The chi square test found this to not be significant (X^2= 2.2329, p= .135101). Although it might be argued that those with scurvy were likely to die younger because of the condition, it is hard to find a reason for such a causation.

In summary, scurvy was relatively consistent across age and sex groups ranging from about 20% to 30%. No statistically significant differences were seen.

Patterns of Scurvy in Individual Bone Elements

This section discusses the patterns of scorbutic lesions found on individual bone elements. This includes the squamous portion of the temporal bone, the greater wings of the sphenoid, and the co-occurrence of lesions on both elements. Only adults were considered for the sex analysis.

Sex

Figure 14 is a representation of the prevalence of lesions associated with scurvy on the squamous portion of the temporal bone and the greater wing of the sphenoid based on sex. For the temporal bone, males had nearly twice the rate of lesions associated with scurvy (21.33%) compared to females (11.63%), but a chi square test determined the difference was not significant (X^2= 1.7063, p= .19147). When presence on individual elements is compared, both sexes showed a higher prevalence of scorbutic lesions on the greater wing compared to the squamous portion of the temporal bone. For this element, males had a higher frequency (24%) than females (16.28%), but a chi square test suggests that the difference was not significant (X^2= .9213, p= 0.33).

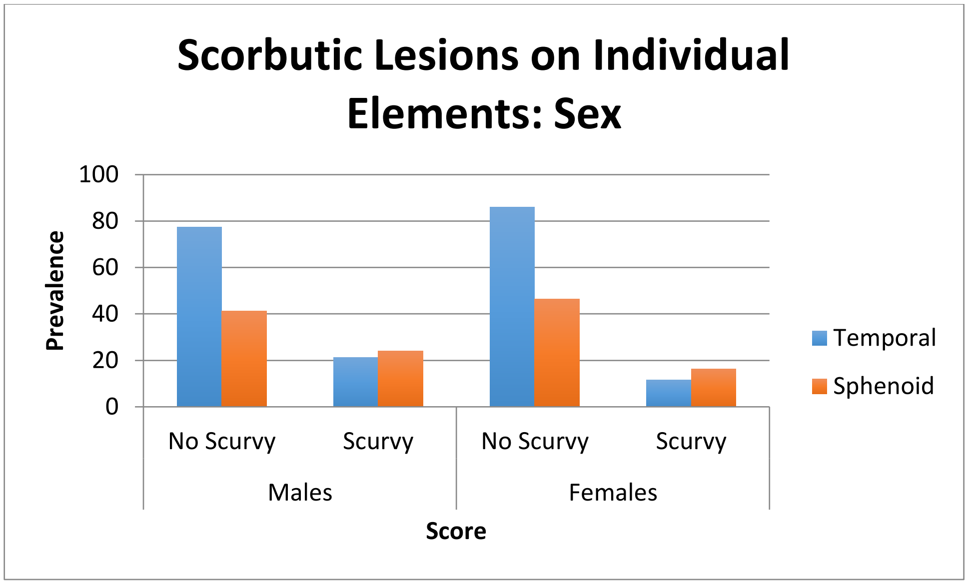

Figure 14. Scorbutic Lesions on Individual Elements: Sex

Both males and females with scurvy had a higher percentage of lesions on the greater wing of the sphenoid, compared to the squamous portion of the temporal bone, and males had a slightly greater frequency, which could be attributed to sexual morphology of the skull. The areas of the skull where the muscles of mastication attach tend to be more pronounced in males, causing the mechanics of chewing to be more rigorous on the surrounding tissues, and leading expression to be more evident in males. Preservation might also be playing a small part in that this is a fragile bone and it is likely to be somewhat thicker in men.

The prevalence of co-occurrence of lesions on both the squamous portion of the temporal bone and the greater wing of the sphenoid shows a similar pattern by sex (figure 15). Males (54.55%) had a higher rate of the co-occurrence of lesions on both bones compared to females (33.33%), but once again the difference was not significant (X^2 = 1.2316, p=0.5406).

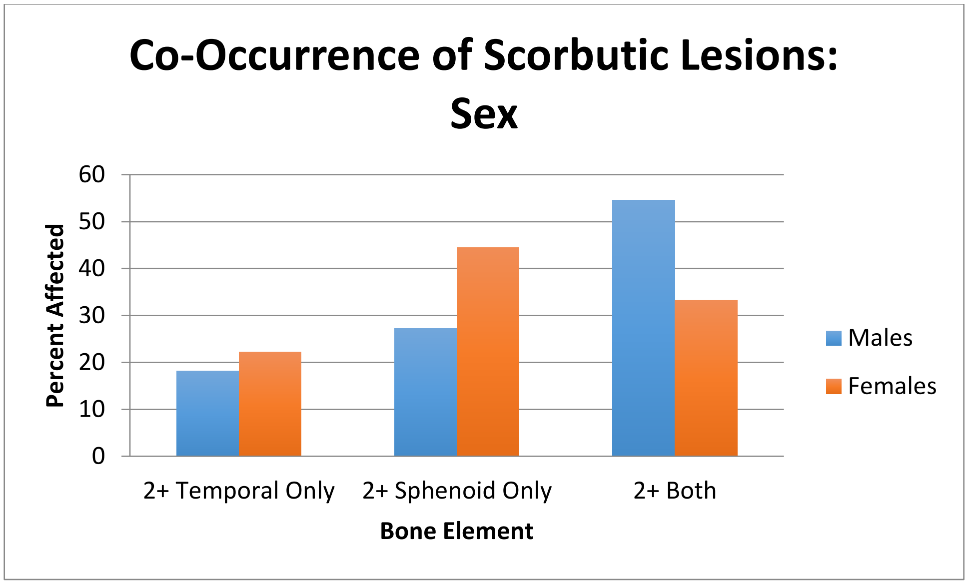

Figure 15. Co-Occurrence of Scorbutic Lesions: Sex

In females, the co-occurrence was not as common as finding scorbutic lesions on the greater wing of the sphenoid only. The co-occurrence was most common in males, which is consistent with the expectation that scurvy was more likely to be observed in males.

Age

Figure 16 shows the prevalence of lesions on the squamous portion of the temporal bone and the greater wing of the sphenoid in sub-adults compared to adults. When looking at the population segments, sub-adults had a higher rate (24%) of lesions on the squamous portion of the temporal bone than that seen in adults (17.8%). A chi-square test was conducted to determine if there were a significant difference between sub-adults and adults, and the results were not significant (X^2= .0.4619, p=. 0.496739). For the greater wing of the sphenoid, sub-adults as a group had a slightly higher rate (24%) than adults (21.19%). The chi-square test was again not significant (X^2 =0.1255, p= 0.723176).

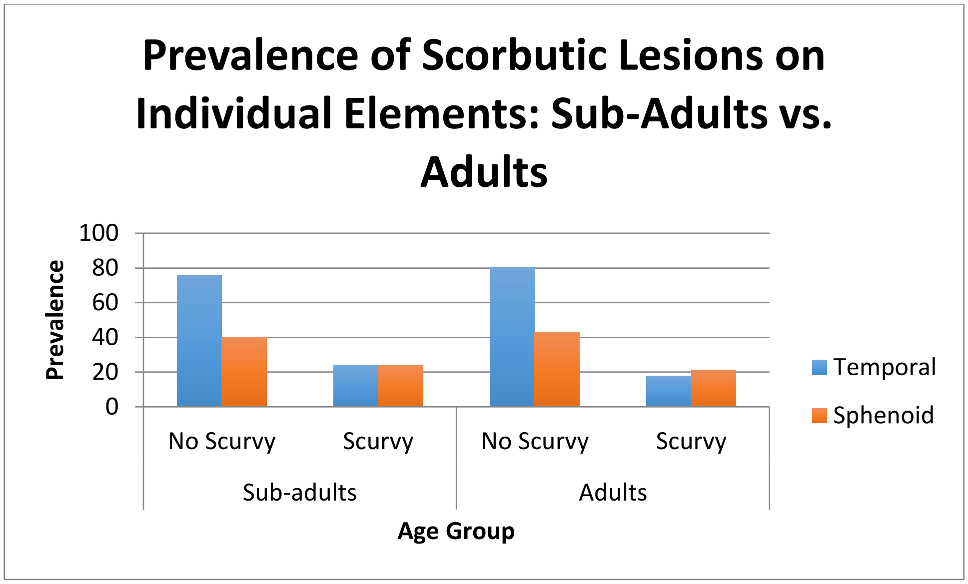

Figure 16. Prevalence of Scorbutic Lesions on Individual Elements: Sub-Adults vs. Adults

Figure 17 breaks down the prevalence of scorbutic lesions on the temporal and greater wing within age groups. Among the sub-adults, individuals between the age of 6 and 15 had nearly twice as many (27.78%) lesions associated with scurvy than the younger sub-adult group (14.29%) on the squamous portion of the temporal bone, which followed the pattern seen for the overall rates for the two age groups. Similarly, adults between the ages of 16 and 29 displayed a higher of lesions (19.54%) compared to those over the age of 30 (12.9%). These results were not significant ($X^2 = 1.7934$, p= .616364). For the greater wing of the sphenoid, when compared within age groups, individuals between the ages of 0 and 5 had a higher prevalence of lesions associated with scurvy (28.57%) than the older group of sub-adults. In adults, those ages 16 through 29 had a higher prevalence (24.14%) than their older counterparts. Again, a chi-square test found these results not significant ($X^2 = 1.736$, p= .628971). Overall, the greater wing of the sphenoid had a slightly higher frequency of lesions associated with scurvy (21.68%) than the squamous portion of the temporal bone. This is consistent with the pattern of the deficiency progression, starting on the sphenoid, and moving towards the temporal bone.

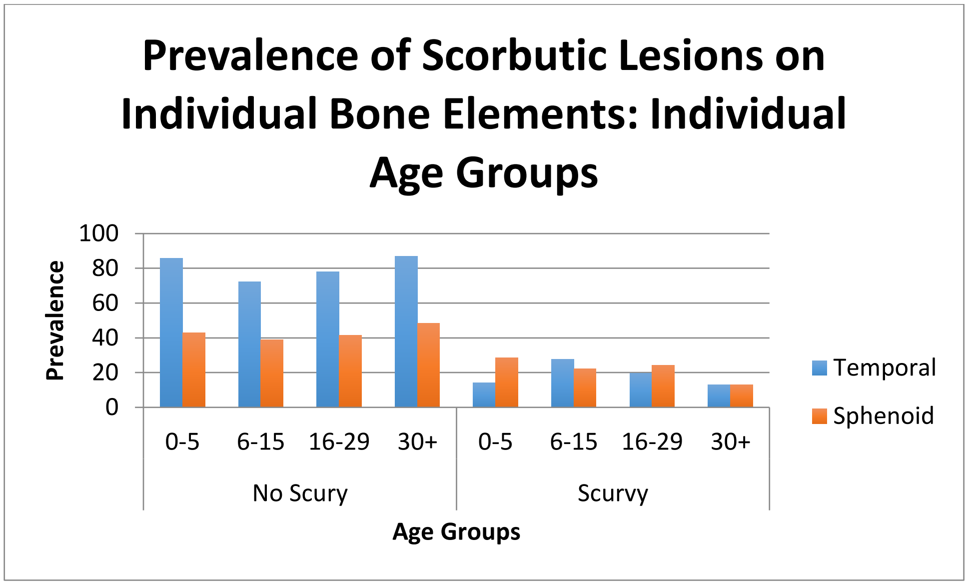

Figure 17. Prevalence of Scorbutic Lesions on Individual Bone Elements: Individual Age Groups

The co-occurrence of scorbutic lesions on both elements between sub-adults and adults (figure 18) follows a similar pattern in both age groups with each having about 50% of individuals showing lesions on both the sphenoid and temporal. As would be expected, the slight differences were not found to be significant (x^2 =. 2111, p= 0.899849).

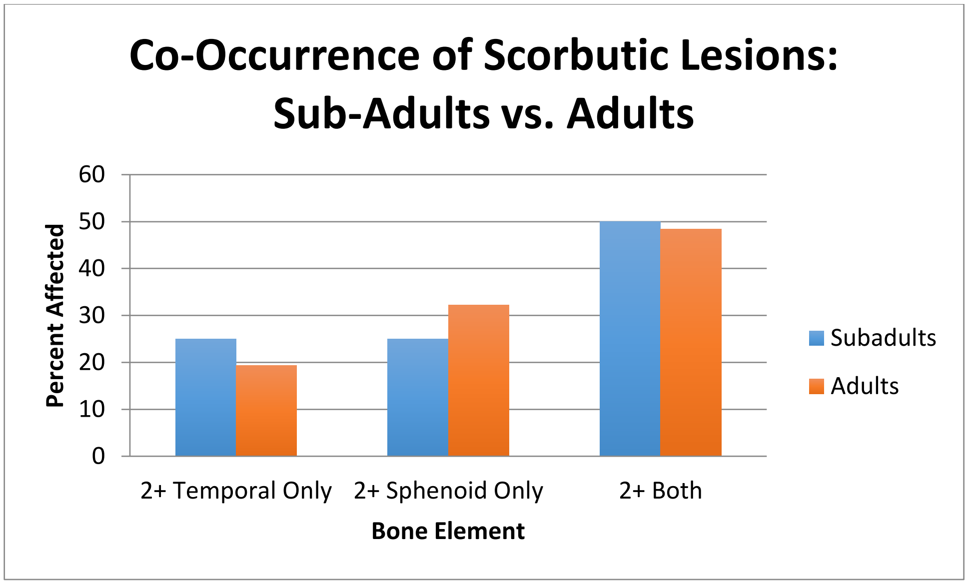

Figure 18. Co-Occurrence of Scorbutic Lesions: Sub-Adults vs. Adults

Figure 19 compares each age group and the percent of co-occurring lesions on both elements. All age groups had approximately half of its individuals exhibit porosities on the sphenoid as well as the temporal, with adults over the age of 30 having the highest prevalence. Generally, the temporal only and sphenoid only classifications had between 18 and 32% prevalence with the exception of the younger children, none of whom had presence on the temporal alone. Because of zero values, a chi-square test for differences could not be conducted, but it would not be expected to reach significance.

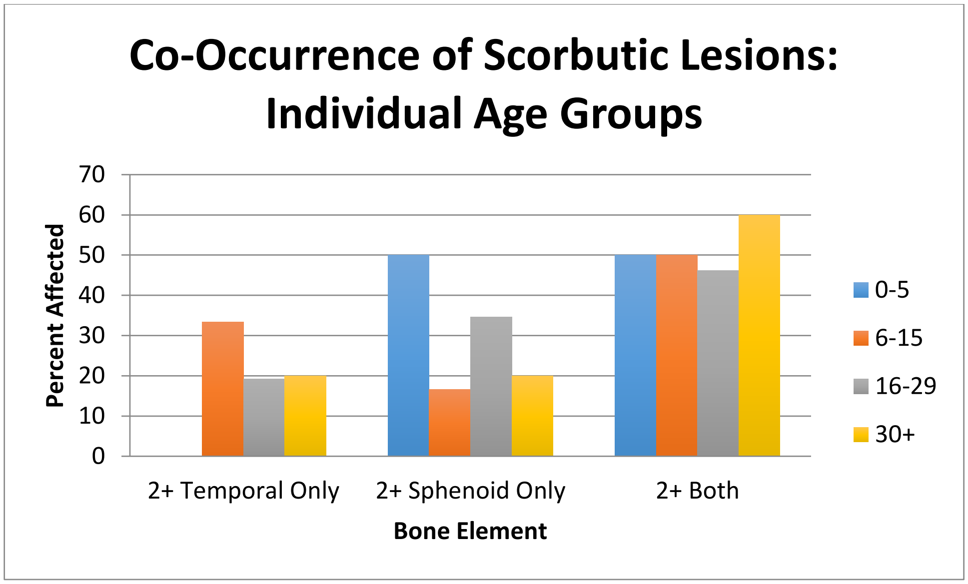

Figure 19. Co-Occurrence of Scorbutic Lesions: Individual Age Groups

This section shows several patterns. First, males had a higher prevalence of lesions compared to females in terms of individual elements and their co-occurrence. Next, sub-adults between the ages of 6 and 15 had a higher prevalence than their sub-adult counterparts in all scored categories except for lesions on the sphenoid. In terms of age, the co-occurrence of scorbutic lesions on both elements was significant. Overall, sub-adults had a higher prevalence in all categories. Lesions were more common on the sphenoid than the temporal bone among the age and sex groups considered.

These patterns are consistent with several studies that argue lesions on the greater wing of the sphenoid are the most indicative of scurvy. Ortner et al. (1999) and Ortner and Erikson (1997) both suggest two reasons for this pattern: (1) the association of the greater wing of the sphenoid with the vascular supply to the temporalis muscle; and (2) the mechanics of mastication associated with the greater wing of the sphenoid. Ortner and Erikson (1997) suggest that the two deep temporal arteries on top of the periosteum on the greater wing of the sphenoid and the squamous portion of the temporal bone could be responsible for the appearance of lesions in these areas and others that are possibly associated with scurvy. They do not provide any discussion on why the greater wing of the sphenoid is more commonly affected than the temporal bone, but it could be related to how these vessels branch from larger arteries. It could also be associated with the delicate nature of the greater wing.

Patterns of Periodontal Disease with Scurvy

Patterns of periodontal disease and antemortem tooth loss occurring with possible scurvy were also investigated based on previous investigations by Saul (1972) and Cohen (1987). Individuals with and without scurvy were evaluated for the presence or absence of alveolar disease, as evidence by alveolar porosity and recession, as well as antemortem tooth loss. Alveolar porosity and recession were scored together, and considered "present" if one or both conditions were observed. Only adults were considered in this analysis due to the developing dentition of sub-adults.

Sex

Figure 20 depicts the presence and absence of periodontal disease, as well as antemortem tooth loss based on sex. When considering periodontal disease, females with scurvy had a 100% occurrence of the condition, which was about 5% higher than males with scurvy. A chi-square test could not be calculated for this comparison because there were no females with scurvy that did not have periodontal disease. Females without scurvy also had a slightly higher rate of the occurrence than their male counterparts. The chi-square results found this not to be significant ($X^2 = 0.0092$, $p = 0.923407$).

Looking at antemortem tooth loss in individuals with scurvy showed that females, again, had a higher rate than males by over 30%. Males without scurvy had a slightly higher rate than females without scurvy by just half a percent. The chi-square results found this not to be significant ($X^2 = 3.15$, p= 0.075929).

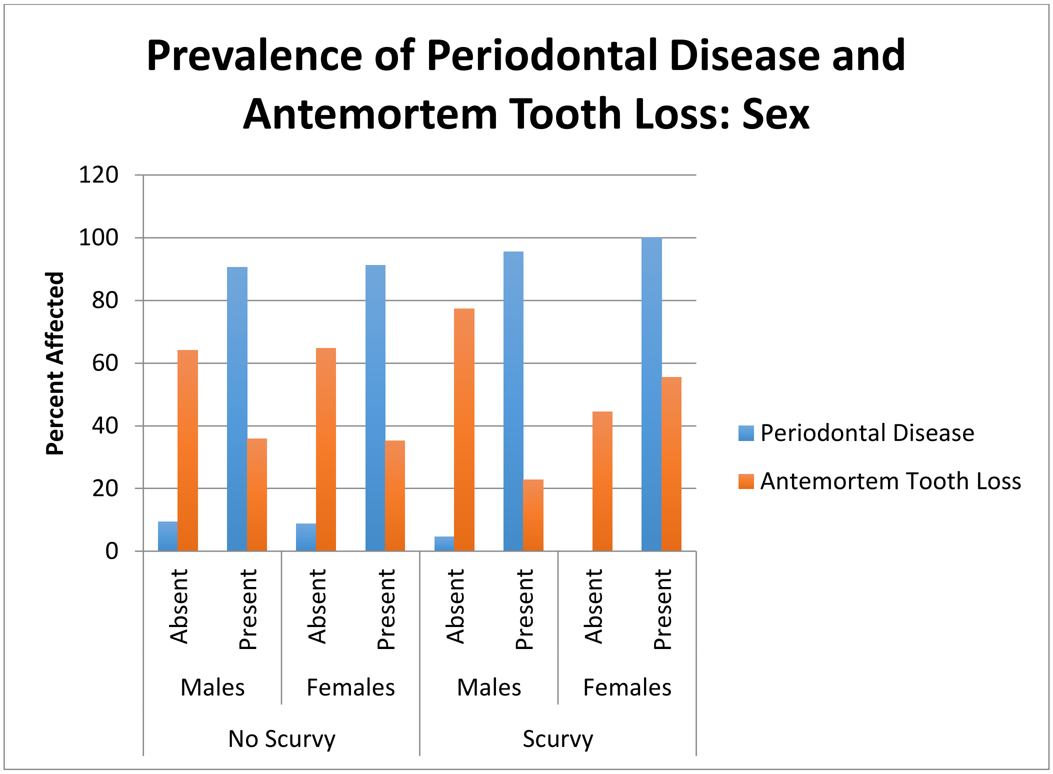

Figure 20. Prevalence of Periodontal Disease and Antemortem Tooth Loss: Sex

Age

Figure 21 looks at the presence and absence of the aforementioned conditions within adults, with and without scurvy. Adults with scurvy had a higher rate of alveolar porosity and recession, but the opposite was found for antemortem tooth loss. While a chi-square test found the difference for periodontal disease not to be significant ($X^2 = 1.8486$, p= 0.173951), the results were significant for antemortem tooth loss ($X^2 = 9.5607$, p= 0.001988).

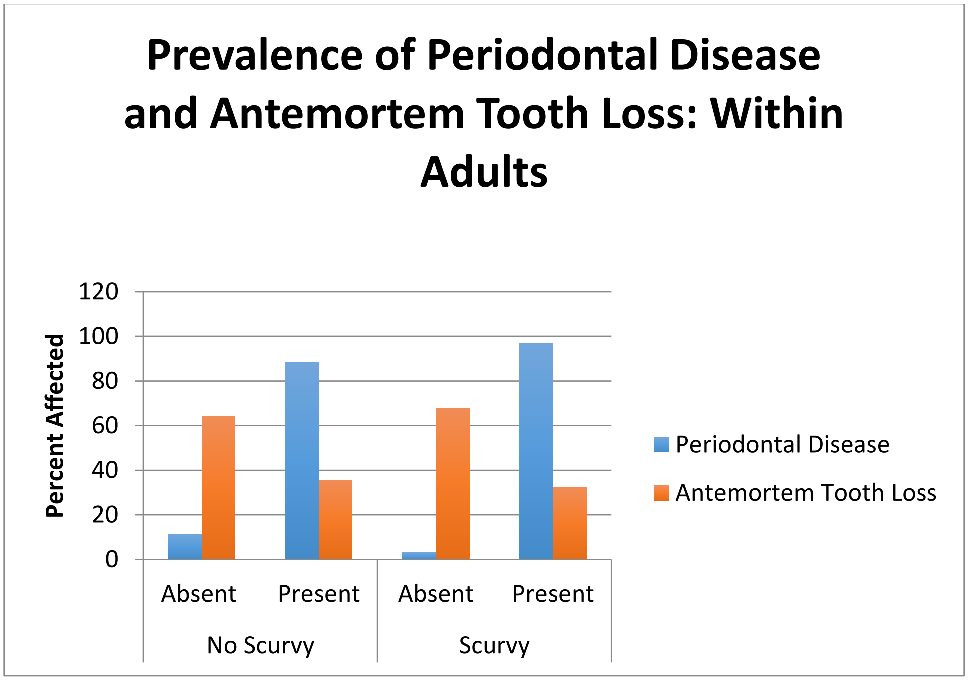

Figure 21. Prevalence of Periodontal Disease and Antemortem Tooth Loss: Within Adults

Figure 22 shows the comparison of these conditions between the adult age groups. Adults between the ages of 16 and 29 with scurvy had the highest rate of periodontal disease, but a chi-square test of the difference that was not significant ($X^2 = 2.3428$, p= .125866). However, the results become more interesting when evaluating antemortem tooth loss. Adults without scurvy over the age of 30 had the highest rate of this condition. The chi-square test comparing both age groups, with and without scurvy, found these results to be significant ($X^2 = 6.1724$, p= 0.012976).

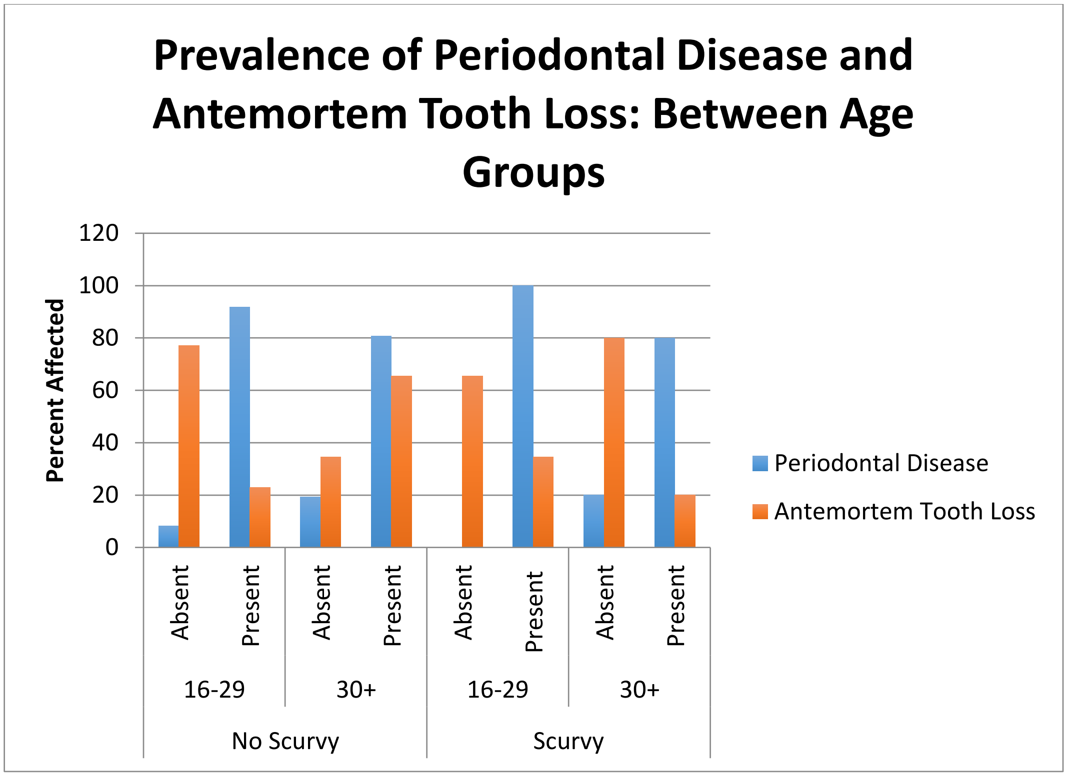

Figure 22. Prevalence of Periodontal Disease and Antemortem Tooth Loss: Between Age Groups

Overall, these results show that females were affected by symptoms of periodontal disease at a higher rate than males, especially females with scurvy. With age, the results were not as consistent, but were revealing nonetheless. Alveolar porosity and recession was more common in adults with scurvy, while antemortem tooth loss was more common in those without. A similar pattern was found within the individual age groups. Antemortem tooth loss was more common in those without scurvy, but the older age group had a higher occurrence, which is consistent with the typical pattern of antemortem tooth loss. The pattern of alveolar degeneration was consistent with the hypothesis that the condition would co-occur with scurvy; however, the hypothesis concerning the co-occurrence of antemortem tooth loss with scurvy was not supported.

Summary

There are several important patterns to consider after the project data was analyzed. Scurvy was found, but in generally low frequencies. Males were more likely to be affected than females, and juveniles had a higher rate than adults. Lesions associated with scurvy on the skull were more frequent on the greater wing of the sphenoid, and the co-occurrence of the lesions on both tested cranial elements in individuals with scurvy was found to be significant. Finally, the co-occurrence of alveolar degeneration in individuals with scurvy is consistent with the diagnostic criteria of scurvy and bleeding gums. However, this could not be supported for antemortem tooth loss, which suggests that scurvy either improved, or did not progress to a severe enough level for tooth loss to occur. Considering these results with past health studies of Tipu, they are consistent with the findings that this was a relatively healthy population during contact.

CHAPTER VI – CONCLUSIONS

This project explored the possible presence of scurvy in the colonial Maya population from Tipu in west central Belize. Using the presence of clearly observable lesions on the greater wings of the sphenoid and/or the squamous portion of the temporal bone, an individual was considered to have possible scurvy. In addition, the presence or absence of periodontal disease, in the form of alveolar porosity and recession, as well as antemortem tooth loss was also recorded in order to establish if there is a co-occurrence between scurvy and these conditions. The scoring system that was developed was applied to 143 individuals who had crania that were at least 50% complete.

This project was conducted for multiple reasons. The first was to contribute to the general understanding of the diagnostic characteristics of scurvy, and to test findings concerning these diagnostics cited in previous literature (Aufderheide and Rodriguez-Martin 1998; Klaus 2015; Ortner 2003; Ortner and Ericksen 1997; Ortner, Kimmerle, and Diez 1999). This was one of the first investigations to look specifically at the co-occurrence of scorbutic cranial lesions in adults. The next reason was to look at the patterns of expression in the population by age, sex, and bone element. Last, the project sought to encourage the possibility of more studies of scurvy in other Maya skeletal populations during the same time period, other tropical non-Maya populations, and other skeletal populations. The Tipu population is one of the very largest and best preserved Maya skeletal collection in existence, which made it ideal in which to explore all of these aspects of scurvy manifestation.

There were several hypotheses addressed in this project:

- The first set of hypotheses concerned the demographic patterns of scurvy in the population. It stated that scurvy would be present at Tipu, but at generally low levels, and that juveniles would display a higher rate of scurvy than adults, but that there will be no significant difference between males and females. Overall, the predicted patterns of differences were seen. The appearance of possible scurvy was found to have a consistently low and mild presence at Tipu, generally affecting between 20 and 35% of all subgroups examined; these results were consistent with prior findings that Tipu is a generally healthy population. The project found that sub-adults had a slightly higher frequency of the condition than adults, with sub-adults between the ages of 6 and 15 having the highest prevalence out of all four age groups, but none of the differences were statistically significant. It was also expected that there would be no significant difference between males and females. Males consistently had a nearly 50% higher prevalence compared to females, but again the results were not significant.
- The second hypothesis states that the appearance of scurvy will be most distinguishable and frequent on the greater wings of the sphenoid. This was tested since this skeletal element has been argued to be the primary diagnostic trait for scurvy (Ortner 2003). In addition, it was expected that lesions would also be common on the squamous portion of the temporal since it shares many of the same muscles with the sphenoid. The analysis of individual bone elements in this project found that the greater wing of the sphenoid was

affected more than the squamous portion of the temporal bone. In most cases, the difference was small (between 3-5%). Lesion co-occurrence was found to be statistically significant when comparing adults to sub-adults, as well as the comparison between all four age groups. This would suggest that the temporal can also be used confidently in diagnosing likely scurvy.

- The final hypothesis stated that scurvy would co-occur with the symptoms of periodontal disease (alveolar degeneration and porosity) and antemortem tooth loss in adults. Again, this was studied in order to test prior findings (Saul 1975; Ortner 1999; Ortner 2009) and add to the diagnostic knowledge of the condition. The hypothesis was generally supported with periodontal disease with females having a somewhat higher correlation than males. However, the same cannot be said about the co-occurrence of scurvy with antemortem tooth loss. In fact, it was more common in older adults without scurvy, which suggests that antemortem tooth loss rates were primarily reflective of advancing age.

It is likely that this nutritional deficiency can be attributed to synergistic health and cultural factors, such as food preparation and storage, rather than related to the political climate of contact at the site of Tipu. The Tipu population, as well as the other tropical populations that were reviewed in this project, had access to foods that were high in vitamin C. This implies that other factors, such food processing methods, were more likely in operation as a cause of the scurvy seen. Since scurvy has been observed in pre-contact Maya populations (Saul 1972; White et al. 2006; Wrobel 2014), it suggests that

European contact was not necessarily a variable. Therefore, the presence of scurvy was likely due to a cultural factor that was present before this political change.

Several issues must be kept in mind when making these interpretations. Differential diagnosis was potentially a major contributing factor to error, especially in terms of the lesions associated with porotic hyperostosis and cribra orbitalia, which are conditions traditionally associated with anemia (Aufderheide and Rodriguez-Martin 1998; Cohen 1987; Klaus 2014). To the naked eye, these lesions look very similar to those associated with scurvy, especially the more mild expressions which are also the more common expression. This was particularly true when trying to distinguish between the lesions on the upper orbits and those found on the squamous portion of the temporal bones and the greater wings of the sphenoid. In addition, photographs in the literature (Aufderheide and Rodriguez-Martin 1998; Ortner 2003; Ortner and Ericksen 1997) were not especially helpful in attempting to distinguish between the separate conditions unless the conditions were severe. This is further complicated by the small amount of academic literature that has been published about scurvy in skeletal populations, especially the post-classic and historic Maya. These issues made it difficult to draw absolute conclusions about the appearance and severity of the lesions, leading to the determination of “possible” scurvy rather than something more definite.

With this specific population, other research into other diagnostic traits of scurvy could be further investigated, including presence of postcranial periosteal lesions of the long bones and the involvement of the ribs. As a whole, more paleopathological studies of scurvy should be conducted, both macroscopically and microscopically, so a more definite set of diagnostic traits for the disease can be ascertained. In addition, a more standardized scoring system needs to be developed in order to understand the development of the disease and aid in accuracy of comparisons of lesion frequency and severity among observers. As well, other Maya populations could be reassessed for scurvy to further investigate cultural practices that might be in operation which contribute to the condition.

This study has contributed to our understanding of scurvy in several ways. On a paleopathological level, this research has added more information on the appearance and identification of the condition. In the biocultural realm, this project has suggested that the Maya were affected by the condition despite the presence of resources high in vitamin C in the environment. This is important since it has implications for interpretation of health issues since it likely has been underestimated the role of scurvy in occurring synergistically with other nutritional factors.

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